DIFFERENCES IN RUNNING GAIT KINEMATICS BETWEEN HIGHLY TRAINED AND RECREATIONAL TRAIL RUNNERS, BEFORE AND AFTER A FATIGUE STIMULUS

by

Emily Jeanne Robertson

Thesis presented in partial fulfillment of the requirement for the degree of Master of Sport Science in the Department of Sport Science, Faculty of Medicine and Health Sciences at Stellenbosch University

Supervisor: Prof. Ranel Venter

Co-supervisor: Mr. Simon de Waal

December 2021

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ACKNOWLEDGEMENTS

My parents, **Ian** and **Sue**, for the opportunity to study a Masters and for believing in me every step of the way even when I didn't believe in myself.

My sister, **Laura**, thank you for every motivational meme, all the meals you made and for listening to me process this whole project for two years.

To **Aidan David** thank you for helping me make decisions and for showing me that research can be fun.

To my **flatmates** over the last two years. There have been a few of you and all your support and understanding made this project easier to do.

Prof. Ranel Venter, your role as a supervisor was so valuable. Thank you for always checking in and being a great support over this time.

Simon de Waal, without you I certainly wouldn't be here. Thank you for believing in me from very early on, I'm so grateful for your open door policy and for your advice as a mentor and a friend.

Oloff, your excel skills and willingness to help out with all things equipment related were greatly appreciated.

Matt, to my favourite person to share an office with. Matt thank you for making me laugh every day of Masters, especially on the days I didn't want to.

The Greylings, thank you for welcoming me into your home, you guys feel like family and your ongoing support of my academic endeavours has been amazing over the last two years.

The **Jonkershoek** family, thank you guys for your excitement to see me succeed. All the coffees, runs, rides, walks through the garden always came at exactly the right time.

The members of the Neuromechanics Unit Lab, **Dr. John Cockroft** for allowing my research project to take place in the laboratory. **Cara Mills** and **Dr. Lara Grobler**, for accommodating so many of my requests, always being up for answering my questions and for just generally being pleasant and helpful to work with.

The **Participants** of this study, for your brilliant effort to further research in this field and for just being incredibly inspiring people to work with.

SUMMARY

The influence of fatigue on running gait kinematics is not well documented in the trail running population, specifically the differences between highly trained and recreational trail runners. Previous research on running gait kinematics has largely focused on road runners, and the relationships between kinematics, performance, injury and fatigue has been established in this population. There is limited research on trail running gait kinematics available and the role thereof in trail running performance and training, in comparison to road running.

Seven highly trained runners (mean age 35 ± 2.2; body mass (kg) 69.5 ± 4.3; height (cm) 177.5 ± 5.8; VO_2max 71.30 ± 6.18) and 10 recreational trail runners (mean age 24.8 ± 2.4; body mass (kg) 78.0 ± 5.1; height (cm) 183.5 ± 6.8; VO_2max 66.20 ± 5.12) participated in this study. Runners completed an indoor maximal treadmill running protocol on a BERTEC treadmill to volitional exhaustion. The treadmill running protocol included a VO_2max test that began at 10.0km/h, with a continuous increase of +1.0km/h per minute and a continuous inclination increase by 0.5% per minute starting at 0.0%. Select running gait kinematics observed included: stride length (SL), stride frequency (SF), ankle angle at contact (ADF), knee flexion (KF), hip flexion (HF) and forward trunk inclination (FTI) were measured by inertial measurement units (IMU's) (100Hz). Running gait kinematics from the last ten seconds of the corresponding minute, at the start (0%), middle (50%) and end (100%) of each individual's VO_2max test, were analyzed. During their laboratory visit, each runner began with a VO2max test. This test involved a warm up of easy jogging at 10km/h, with a continuous increase of +1.0km/h per minute and continuous inclination increase by 0.5% per minute starting at 0.0%. The runners were verbally encouraged during the test to run for the longest time possible until volitional exhaustion was reached. Results indicated that there were no significant differences between groups during submaximal running (10km/h). When analyzing the changes in kinematics at the start of the VO2max test, there were no significant differences found between the groups in a non-fatigued state during submaximal running (10km/h). Results from the end of the VO_2max test indicated that there were no significant differences between the groups for SC, ADF, HF and FTI. However, significant differences were observed for SL ($p = 0.01$) and KF ($p = 0.02$) at the end of the VO_2max test ($p = 0.02$). Results from the repeated measures ANCOVA indicate that running gait kinematics for both groups were similar. Although no statistical significance was shown, medium to large effect sizes illustrate that there were a trend of kinematic change over time and between groups, that could show significant differences between recreational and highly trained runners with a larger group of participants. *Significance* HT runners maintained a stable running gait for longer, whereas recreational runners can improve in areas such as SL and KF. These results can help to further understanding of the relationship between running gait kinematics, training status and fatigue.

Keywords: Trail running, kinematics, treadmill, fatigue, VO_2max

OPSOMMING

Daar is ‘n gebrek aan goeie navorsing oor die invloed van moegheid op hardloopgang kinematika, veral tussen die hardlopers wat teen hoë intensiteit oefen en die wat slegs oefen vir ontspanning/ rekreasie. Meeste van die navorsing oor hardloopgang kinematika is gebaseer op padatlete en die verwantskap tussen kinematika, prestasie, beserings en uitputting vir die padhardloop populasie. Daar is dus beperkte navorsing beskikbaar op berghardloop hardloopgang kinematika en die rol daarvan op berghardloopprestasie en oefen in vergelyking met padhardloop.

Sewe goed gekondisioneerde hardlopers (gemiddelde ouderdom 35 ±2.2; liggaamsgewig (kg) 69.5 ± 4.3; lengte (cm) 177.5 ± 5.8; VO_2max 71.30 ± 6.18) en 10 ontspanning/ sosiale hardlopers (gemiddelde ouderdom 24.8 ± 2.4; liggaamsgewig (kg) 78.0 ± 5.1; lengte (cm) 183.5 ± 6.18; VO2 max 66.20 ± 5.12) het deelgeneem aan die studie. Die hardlopers het ‘n binnenshuise maksimale trapmeul harloop protokol gedoen, op a BERTEC trapmeul om vrywillige self-bepaalde uitputting te bepaal. Die trapmeul se harloop protokol het ‘n VO_2maks toets ingesluit wat by 10.00 km/h begin het, met ‘n gelydelike toename van +1.0km/h per minuutasook ’n geleidelike toename in die helling van 0.5% per minuut vanaf 0.0%. Hardloopgang kinematika wat tydens die studie geobserveer en met inersie meet-toerusting (100Hz) gemeet is, is sluit in: tree lengte (SL), tree-frekwensie (SF), enkel hoek met kontak (ADF), knie- (KF) en heupfleksie, (HF), vorentoe leun van die romp (FTI). Hardloopgang kinematika van die laaste tien (10) sekondes van ‘n minuut van elke individu se VO_2maks toets is geanaliseer – die begin (0%), middel (50%) en einde (100%). Daar is deurlopend ‘n beduidende statistiese verskil in al die hardloopgang kinematika gevind vir beide die groepe hardlopers (gekondisioneerde harlopers en die wat harloop vir ontspanning) se VO_2maks toets veranderlikes (SL: 2.57 ± 0.35 vs 2.73 ± 0.32m; SC: 169.18 ± 8.77 vs 187.65 ± 11.14 steps per minute; ADF: -4.75 ± 7.66 vs –8.02 ± 5.69°; KF: 14.59 ± 5.63 vs 25.98 ± 6.16°; HF: 19.76 ± 5.25 vs 34.14 ± 6.08°; FTI: 20.0 ± 5.53 vs 21.60 ± 5.99°).

Met die aanvang van die VO_2maks toets was daar geen beduidende statistiese verskil tussen die geobserveerde hardloopgang kinematika van die twee harloop groepe nie. Aan die einde van die VO_2maks toets, was daar steeds nie ‘n beduidende statistiese verskil vir die groepe SC, ADF, HF en FTL nie. Aan die einde van die VO_2maks toets is beduidende verskille wel geobserveer vir SL (2.89 ± 0.22 (HT) vs 2.50 ± 0.31m (REC) $p < 0.01$) en KF (23.20 ± 5.90 (HT) vs 29.95 ± 4.21 (REC) $p < 0.05$).

Alhoewel nie statisties beduidend nie, was daar matige tot baie groot verskille geobserveer by beide groepe wanneer hul uitgeput was (SC: $\eta_p^2 = 0.06$, SL: $\eta_p^2 = 0.11$, KF: $\eta_p^2 = 0.20$, FTI: $\eta_p^2 = 0.31$). *Betekenisvolheid:* Gekondisioneerde hardlopers kon 'n stabiele hardloophang kinematika vir langer handhaaf, sosiale hardlopers kan verbeter in areas van SL en KF. Hierdie resultate sal in die toekoms help om die verwantskap tussen hardloopgang kinematika, staat van oefening en uitputting in hardlopers beter te verstaan.

Sleutelwoorde: berg hardloop, kinematika, trapmeul, uitputting, VO_2maks

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LIST OF ABBREVIATIONS AND ACRONYMS

% :	Percentage
α :	Significance level
β :	Chance of a type 2 statistical error
AF:	Ankle dorsiflexion
AP :	Anteroposterior
ASIS :	Anterior superior iliac spine
BLa :	Blood lactate
BMI :	Body Mass Index
CAF :	Central Analytical Facilities
cm :	Centimetres
CoM :	Centre of Mass
EMG :	Electromyography
FTI :	Forward Trunk Inclination
G :	Grams
GCT :	Ground Contact Time
HF :	Hip flexion
HR :	Heart rate
Hz :	Hertz
ICF :	Informed Consent Form
IMU :	Inertial Measurement Unit
ITRA :	International Trail Running Association
KF :	Knee flexion

kg :	Kilograms
km :	Kilometres
km/h :	Kilometres per hour
lab:	Laboratory
LT :	Lactate Threshold
m :	Metre(s)
m/s :	Metres per second (velocity)
MEMS :	Microelectrochemical systems
ml/kg/km:	millilitres per kilogram per minute
n :	Sample size
RE :	Running economy
RER :	Respiratory exchange ratio
RPE :	Rate of perceived exertion
RR :	Road running
SC:	Step cadence
SF :	Stride frequency
SL :	Stride length
TI :	Trunk Inclination
TR :	Trail running
TRD :	Treadmill running
TTE :	Time to exhaustion
UTCT :	Ultra Trail Cape Town
$VO2$:	Oxygen Uptake
VO_2max :	Maximal Oxygen Uptake
vs. :	Versus

VT : Vertical

OVERVIEW

The present thesis is an article-format thesis. Chapter One provides basic information as background to the study, as well as the aims and objectives which guided the research. An in-depth explanation of research pertaining to the current study is discussed in Chapter Two. Chapter Three explains the methodology used for data collection. Chapter Four contains the article *Changes in running gait kinematics of highly trained and recreational trail runners after an adapted trail running VO_2max test.* This article focuses specifically on the differences in running gait kinematics between two groups of trail runners after an adapted exhaustive ramp incremental test. The article is written according to the guidelines of Gait & Posture. The referencing style in the article is compiled through Mendeley and follows the guidelines as provided for the intended journal. Refer to Appendix A for the author guidelines of Gait & Posture. In Chapter Five, a general discussion and conclusion to this investigation is presented, as well as study limitations and recommendations for future research., thereafter, the Appendices will follow. Refer to Appendices A for the author guidelines as provided by the respective journal, B for the participant recruitment flyer, C for the Participant Information leaflet and informed consent form (English), D for the Participant Information leaflet and informed consent form (Afrikaans), E for the ethical approval letter and F for figure permission from respective journals. The referencing format for this thesis follows the Harvard Referencing style available by Mendeley.

CHAPTER ONE - INTRODUCTION

1.1 BACKGROUND

The popularity of road running as a recreational pastime is ever growing, as evidenced by the increasing number of participants at marathon and ultra-marathon races around the world (Buman, Omli, Giacobbi and Brewer, 2008). Over time, individuals who run have expanded their training and racing to include off-road running. Trail running, a type of off-road running (Scheer et al, 2020) is also gaining in popularity, with an increase in the number of participants and races globally (David and Lehecka, 2013). Trail running is a relatively new sport in comparison to traditional road running, with the difference in surface being the most obvious difference between the two types of running. In the five years between 2009 and 2013, the number of finishers in these types of events increased by 40% to over 4 million participants in 2013 in the USA alone (Gantz and Derrick, 2017). In the South African context, trail running has increased in popularity for both elite and recreational runners, with over 102 ultra-marathon races filling the yearly calendar (Istvan et al, 2019).

Trail running racing, defined by the International Trail Running Association (ITRA) as off-road foot races in a natural environment with minimal paved or asphalt roads (Malliaropoulos, Mertyri and Tsaklis, 2015), has recently been included as an official sport by the International Association of Athletics Federations (IAAF) (Scheer, Ramme, Reinsberger and Heitkamp, 2018). This category of running has no restrictions on distance or elevation change. On most occasions the trail running races require athletes to be self-sufficient between aid stations by carrying food, water and safety equipment (Scheer et al, 2020). According to Scheer et al (2018), in order to be classified as a trail runner, approximately ~50% of a runner’s training and race volume must be on trails with the remaining volume, split between road and track surfaces.

Much of the previous research on running has focused on injury mechanism and prevalence (Malliaropolous et al, 2015; Barton et al, 2016), fatigue (Giandolini et al, 2016), running economy (Tartaruga et al, 2013) and other physiological demands (Fornasiero et al, 2017) through the analysis of kinematic and spatiotemporal running patterns (Riazati, Caplan and Hayes, 2019). As well as these variables, well-researched elements of running-related studies include the effect of surface (Schütte et al, 2016), speed (Billat and Koralsztein, 1996), training status, as well as distance (García-Pérez et al, 2014) on running gait kinematics. An example of commonly reported findings includes the relationship between changes in running speed and ground contact time (GCT) on a road or flat surface – the amount of time a runner's foot remains in contact with the ground (Kim, Mirjalili and Fernandez, 2018) – whereby GCT decreases as running speed increases. However, there is little research that describes kinematic changes for trail runners on a trail surface, under the influence of similar conditions.

To a considerable extent, the above-mentioned studies focus mainly on the performance of two distinguishable classes of runner, highly trained (Easthope et al, 2018) or recreational (Dierks, Manal, Hamill and Davis, 2010; Koblbauer, van Schooten, Verhagen and van Dieen, 2014). Studies comparing kinematic differences between these two groups of runners are less common and fewer still focus on this comparison within the trail running population. Currently, little is known about the differences between highly trained and recreational running kinematics, as a large portion of studies target highly trained runners and not running gait in recreational runners (Moore, Jones and Dixon, 2012).

Within the current body of literature on running gait kinematics, the effect of surface, gradient and duration (length of time spent running) have been well investigated due to the role they play in adaptations of running gait and kinematics. Trail runners need to be able to navigate technical, uneven terrain over long distances, placing a large demand on their endurance ability as well as the skills used to maintain technique to navigate those surfaces effectively. Running on uneven terrain causes changes and increased variability in running gait kinematics such as, step width, step length, and ground contact time (Kim, Mirjalili and Fernandez, 2018) as compared to running on smooth terrain (Voloshina and Ferris, 2015). Voloshina and Ferris (2015) found that step width and stride length variability increased by 27 and 26% respectively when running on uneven surfaces in comparison to smooth surfaces.

Running gait kinematics research is typically conducted in a closed environment, on a treadmill in a laboratory. However, research indicates that treadmill running gait kinematics are consistent with typical overground running. There have been some conflicting results as to the validity of treadmill derived running kinematics and kinetics in comparison to overground running (Lavanska, Taylor and Schache, 2005). Recent literature, however, indicates that many spatiotemporal, kinematic, kinetic outcomes measures, as well as physiological and perceptual performance measures are largely comparable between motorized treadmill and overground running. Regarding physiological and perceptual performance measures, Miller et al, (2019) reported that heart rate (HR) and rate of perceived exertion (RPE) were similar during near-maximal motorised treadmill running compared to overground running. Maximal motorised treadmill running caused similar VO_2 and HR responses to overground running (Miller et al, 2019). In a systematic review and meta-analysis of 33 cross-over studies (n = 494 participants), Van Hooren et al, (2020) concluded that spatiotemporal, kinematic, kinetic, muscle activity, and muscle–tendon outcome measures are largely comparable between motorized treadmill and overground running.

Treadmill running for research purposes has a number of advantages. Riazati et al, (2019) have indicated that treadmill running offers a more consistent environment to collect continuous data at a constant speed. Other advantages of treadmills, compared with overground running, is that various physiological measures can be captured within a limited and controlled space, greater control exists over performance variables such as running velocity and surface gradient, and there is greater control over environmental variables such as ambient temperature, wind speed and relative humidity when compared with outdoor running (Miller et al, 2019).

Training terrain is an important aspect to consider when selecting a test protocol involving trail runners due to the possible effect on running gait kinematics. It is generally understood that trail runners are better conditioned for incline running and may perform better at an inclined protocol during the assessment of cardiorespiratory fitness, for which maximum oxygen uptake (VO_{2max}) is a valid proxy, compared to a flat protocol (Ferley and Vukovich, 2015; Scheer et al, 2018).

Lastly, it is apparent that a runner's training status may influence their running gait kinematics with highly trained runners demonstrating a preferred stride frequency that is closer to their optimal stride frequency than that of their recreational counterparts, possibly due to their experience whereby highly trained runners have enhanced their efficiency to a greater extent over time (de Ruiter et al, 2013). This preferred stride length-frequency combination results in what might be termed "*self-optimization*" (Hunter and Smith, 2007, p. 653-661). This idea of self-optimization has been well researched whereby; most runners naturally choose a stride length-frequency combination, which minimizes the metabolic cost (Cavanagh and Williams 1982), however highly trained runners may be able to minimize this metabolic cost to a greater extent. This process seems to take place even under fatigue, however, recreational runners spend more time running at suboptimal stride frequency than highly trained runners (de Ruiter et al, 2013).

1.2 PROBLEM STATEMENT AND RATIONALE FOR THE STUDY

The recent increase in the popularity of trail running has not coincided with an increase in trail running research. There is little evidence-based trail running-specific literature on offer for runners starting out in the sport, or for already established athletes to improve their knowledge of various topics that could possibly influence their performance and injury risk management.

Much of the global research on trail running kinetics and kinematics, focuses specifically on highly trained runners. However there has been little research published on either highly trained or recreational trail runners in South Africa. A between-group study of recreational and highly trained trail runners should allow for the determination of differences in performance and potentially notice markers that can be useful to improving running gait kinematics.

Research on the effect of fatigue on trail runners and their kinematics is essential for researchers to better understand the changes in running gait kinematics during exhaustive trail running efforts. Once a comprehensive understanding of these changes in running gait kinematics has been achieved, both in recreational and highly trained runners, coaches and athletes will be better placed to implement training interventions that aim to delay these changes, thereby optimising performance.

The current study examined the effect that a trail specific fatigue protocol, namely at incline, had on the running kinematics of highly trained and recreational trail runners and to adds to the body of literature surrounding the effects of fatigue on the running kinematics of trail runners. Results from the study could assist coaches and trail runners in understanding the effect of fatigue on running gait kinematics for trail runners. These results and future recommendations could assist technical coaches with their analyses of the trail runners and potentially be used to develop running specific training programs that improve fatigue resistance and therefore performance for both highly trained and recreational runners (Smoliga, Myers, Redfern and Lephart, 2009). An in-depth understanding of running gait allows for coaches, physicians, and athletes to recognize the different mechanisms of performance, injury and fatigue, with which they could help to facilitate improved performance based on the information they observed (Dugan and Bhat, 2005).

1.3 RESEARCH QUESTIONS, AIMS, OBJECTIVES AND HYPOTHESES

Research Question One

Do highly trained trail runners have different running gait kinematics, during submaximal level treadmill running (0° incline and 10km/h), compared to recreational trail runners?

Research Aim One

The first aim of the present study was to determine differences in selected running gait kinematics between highly trained and recreational trail runners during submaximal level treadmill running.

Objectives

The objectives were to determine differences in:

1. stride length,
2. step frequency (cadence),
3. forward trunk inclination, and
4. angles of hip, knee and ankle at contact in the sagittal plane

during submaximal, level running between recreational and highly trained trail runners who ran on an instrumented BERTEC treadmill wearing Inertial Measurements units (IMUs).

Hypotheses statement

Research hypothesis: It was hypothesized that highly trained trail runners will have longer strides; lower step frequency; greater trunk inclination and increased hip, knee and ankle dorsiflexion at contact compared to recreational trail runners.

The null hypothesis (H0) for the preceding research hypothesis stated that there would be no significant differences between the highly trained and recreational trail runners for the mentioned kinematic variables during submaximal level treadmill running (H0: $\mu 1= \mu 2$). The alternative hypothesis (H1) stated that the means are not all equal between the mentioned kinematic variables during submaximal level treadmill running in highly trained and recreational trail runners.

Research Question Two

How will a treadmill run to exhaustion affect the running gait kinematics of highly trained and recreational trail runners?

Research Aim Two

To determine changes in selected running gait kinematics of highly trained and recreational trail runners over time, during an adapted trail running VO_{2max} test.

Objectives

The objectives were to analyse running gait kinematics from the last ten seconds of the corresponding minute, at the start (0%), middle (50%) and end (100%) of each individuals VO_{2max} test, to compare differences in the following variables, namely;

1. stride length,
2. step frequency (cadence),
3. forward trunk inclination, and
4. angles of the hip, knee and ankle at contact in the sagittal plane

Hypothesis statement

Research hypothesis: It was hypothesized that highly trained runners will maintain their pre-fatigue gait kinematics to a greater extent than recreational runners under various levels fatigue during an adapted trail running VO_2max test.

The null hypothesis (H0) for the preceding research hypothesis stated that there would be no significant differences between the highly trained and recreational trail runners for the mentioned kinematics during the adapted trail running VO_2max test (H0: µ1= µ2). The alternative hypothesis (H1) stated that the means are not all equal between the mentioned kinematic variables after the adapted trail running VO_2max max in highly trained and recreational trail runners.

1.4 VARIABLES

The dependent, independent, categorical and control variables applicable to current study are listed in Table 1.1.

Table 1.1: Table of variables related to each hypothesis of the study.

Hypotheses	Dependent variables	Independent variables	Categorical variables	Control variables
1. Differences at submaximal running	Step cadence	Training Status	Highly Trained	Running speed
	Stride length	Recreational	Recreational	Surface incline
	Angles of ankle, knee and hip at contact			
	Forward trunk inclination			
2. Differences at mid-point (50% competition)	Step cadence Stride length Angles of ankle, knee and hip at contact Forward trunk inclination	Training Status Recreational	Highly Trained Recreational	Running speed Surface incline
3. Differences at maximal running	Step cadence	Training Status	Highly Trained	Running speed
	Stride length		Recreational	Surface incline
	Angles of ankle, knee and hip at contact Forward trunk inclination			

1.5 ASSUMPTIONS

The following assumptions were made regarding the study: (a) that the runners were truthful about their weekly training mileage, (b) that the runners performed to the best of their abilities during data collection (c) that the instruments used elicited valid and reliable responses, and (d) that runners adhered to the request of being rested, not using alcohol or caffeine 24 hours prior to testing, and that they ran in their trail shoes.

CHAPTER TWO - THEORETICAL CONTEXT

2.1 INTRODUCTION

Trail running is gaining in popularity, with an increase in the number participants and races around the world (David and Lehecka, 2013). Researchers have started to investigate differences between road runners and trail runners from various points of interest. A number of factors are unique to trail running, including regular periods of various gradients of incline and decline running over constantly changing uneven terrain, as well as the long duration of many trail events. Currently, there is still little research on the influence of the mentioned trail running environment, as well as event-related fatigue, on the running gait kinematics of trail runners. Within the context of the current study, literature on running gait will be presented in terms of running kinematics and kinetics, the influence of speed, inclination, fatigue and training status on running kinematics, as well as the relationship between running gait kinematics and running economy.

"Proper running biomechanics involves synchronous movements of all the components of the kinetic chain" (Dugan and Bhat, 2005, p. 603). Running and walking play different roles in the act of human locomotion, however they serve a similar purpose in that they allow humans to move from one point of reference to another (Dicharry, 2010). Due to individualized running styles, asymmetry and imbalances that occur during the gait cycle, it is difficult to determine "proper" running mechanics and the effect that they have on fatigue, injuries, performance. Therefore, the current study aims to identify trends or habits that could constitute "good" running mechanics for trail runners.

2.2 THE GAIT CYCLE

Running gait is a complex human activity that allows humans to move between two points of interest faster than if they were walking (Dicharry et al, 2010). A clear element of running gait that distinguishes it from walking is the flight phase where both the runner's feet are off the ground at the same time, as opposed to walking, when one limb has contact with the ground at all times (Dicharry, 2010). Additionally, the time in flight and stance phase differ between running and walking whereby, "During the walking gait cycle, approximately 60% of time is spent in stance phase and 40% in swing." (Dicharry, 2010, p. 349) whereas with running, this is almost reversed, and a runner spends greater than 60% of their time in the swing phase. In order to understand running gait, it can be broken down into different phases (Figure 2.1). The stance phase of running consists of force absorption and propulsion. The swing phase can be split into initial and terminal swing with the float phase occurring at the start of the initial swing and the end of the terminal swing (Dugan and Bhat, 2005). Running speed also influences running gait, kinetics and kinematics whereby any change in speed causes a change in corresponding mechanics. Cappellini, Ivanenko, Poppele and Lacquaniti (2006, p. 3462), for example, reported that the gait transition is "accompanied by an abrupt decrease in ground contact time by 35% and an 50% increase in peak ground reaction force". Stride length and duration tend to increase while stance duration decreases with increasing speed in both walking and running (Cappellini et al, 2006). Therefore, when evaluating running mechanics, it is important to standardise the speed of movement at a given level of effort to allow for better between-subject comparisons. Furthermore, given the high degree of inter-individual differences, it is also necessary to normalise the gait kinetics and kinematics to the duration of the stride (see Figure 2.1). The latter processes would allow for more accurate kinetic and kinematic comparisons between different gait speeds, which would be true for both walking and running.

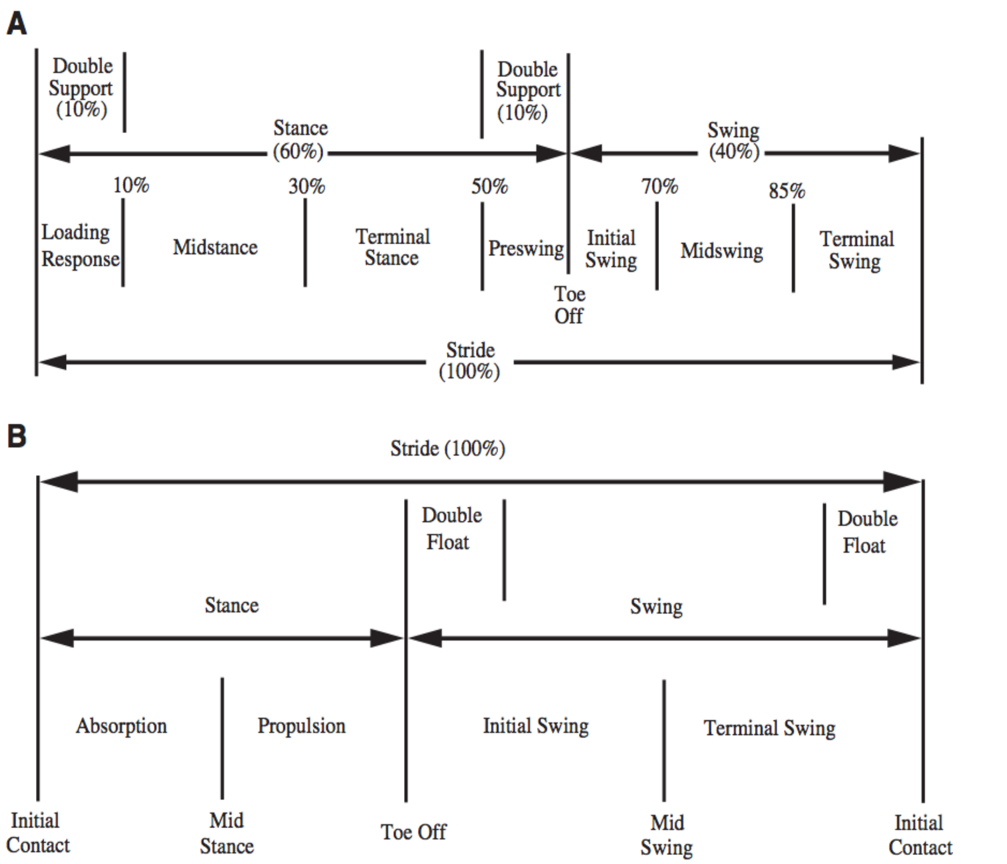

Figure 2.1: Differences in various gait cycle phases and individual components during (A) walking and (B) running (Dughan & Bhat, 2005). (With permission from Elsevier. See Appendix F).

2.3 TRAIL RUNNING

Trail running has not been well-documented in the scientific literature in comparison to road running as research observations in varying terrains and locations are difficult to complete. Defining trail running has also been a challenge. The International Trail Running Associations (ITRA) defines trail running (races) as, “a pedestrian race open to all, in a natural environment (mountain, desert, forest, plain) with minimal possible paved or asphalt road, that should not exceed 20% of the total course. The terrain varies from dirt road, forest trail to single track.” (Malliaropoulos et al, 2015, p. 51). Additionally, Fornasiero et al. (2017) described trail running as a mountain run highlighting that the terrain where these races take place is not standardised by environment, gradient or distance as with road running. To be classified as a trail runner, the majority of a runners' training and competition has to be undertaken on trail surfaces (48%) followed by road (37%) and then track (15%) (Scheer et al, 2018). It is clear that trail running poses a unique physiological and biomechanical challenge to the individual, and it is therefore important to contextualise the factors that may affect running kinematics, especially in terms of trail running.

2.4 FACTORS AFFECTING RUNNING KINEMATICS

Finding a biomechanically sounds running profile and the development of said profile has proven to be a challenging task for researchers. One of the reasons for this complexity is due to the variety of factors that affect running gait kinematics. It could be postulated that trial running on uneven, natural terrain with obstacles would influence and alter running biomechanics. In the following section, factors specific to the aims of the current study will be presented, namely how running speed, running at incline, training status, as well as fatigue could affect running gait kinematics.

Kinematics such as vertical oscillation, ground contact time, foot strike pattern and leg clearance are significantly different in trail running when compared to road running (Voloshina and Ferris, 2015). It was found that step length and width increase when running on an uneven terrain in comparison to a smooth terrain, illustrating the effect that surface smoothness, such as road (even) or trail (uneven), can have on both running kinematics and energy cost (Voloshina and Ferris, 2015). During running, a narrow step width, closer to the midline of the body, is preferred as it reduces lateral moments around the center of mass, allowing for reduced energetic cost compared to larger step width (Arellano and Kram, 2011; Cavanagh 1987).

The effect of speed and incline on running gait kinematics such as stride length (SL) and stride frequency (SF) has been well researched, with both variables increasing linearly as speed increases. Preece et al, (2016) investigated 28 runners (14 recreational, 13 elite) completing four different running speeds (ranging from 3.3 to 5.6 m/s) in order to measure the effect of speed on thoracic inclination (or forward trunk lean). Their results showed that the elite runners maintained their gait kinematics and a consistent thoracic inclination across all speeds. whereas the recreational group however, exhibited a one degree increase in inclination for every 1 m/s increase in speed. There are fewer studies that document the effect of incline or decline running on running gait kinematics. It is possible that highly trained runners have developed specific running gait kinematics to manage the increased speeds at which they perform, differing from recreational runners (Preece, Mason and Bramah, 2016). Presently however, such insights remain speculative and would require further research to substantiate.

Owing to the differing terrain profile of trail running, characterized by a succession of up and downhill off-road sections, the muscle actions required and associated mechanical responses are typically different to that of road running (Ehrström et al, 2018). The mechanical response to road running is largely characterized by similar, repeated, and continuous stretch shortening cycles for lower limb extensors. The mechanical demand for athletes on a trail is usually greater compared to level road running (Dewolf et al, 2016). In level running the oscillation of the center of mass is largely equal, whereas during inclined running, this equal “bouncing” mechanism decreases and disappears as speed and/or slope increase (references?). Further differences include significant changes in ground reaction forces that are observed when moving from a steep downhill to a steep uphill. These changes in slope trigger a specific mechanical response, which is likely to influence the modality of muscular contraction and metabolic demand (Ehström et al, 2018). These specific mechanical responses caused by trail terrain illustrate that different running kinematics are required for trail running compared to road running.

It is known that biomechanical, neuromuscular and physiological adaptations take place during graded or uphill running (Padulo, Powell, Milia and Ardigò, 2013; Vernillo et al, 2016). The extent of this change however is dependent on the steepness of the gradient. Typically, uphill running is seen to cause an increase in step frequency, a shortened stride length, a shorter swing/arial phase duration and an increase in energy expenditure (Padulo et al, 2013). As well as this, gradient alters foot strike pattern as runners navigate the terrain changes (Vernillo et al, 2016 ; Voloshina and Ferris 2015). Changes in knee and hip flexion at contact are also reported for uphill running when compared to level running. At a 30% gradient, knee flexion showed to be more flexed at foot strike than during level running (59.7° vs 21.0°) and greater hip flexion was reported under the same conditions (Vernillo et al, 2016). Padulo et al, (2013) found that increases in stride frequency by 2% were found between 0-2% gradient and a 4.8% increase when gradient increases up to 7%. These increases in stride frequency were coupled with relative decreases in stride length. These results indicated that trained athletes make use of a strategy of adjustment based on the terrain they are faced with, managing changes in step frequency and length in order to control the metabolic cost of running.

2.4.1 TRAINING STATUS

Evidence suggests that select kinematic differences can be observed between recreational and highly trained runners (Buman, Omli, Giacobbi and Brewer, 2007; Scheer et al, 2018), however there is a lack of consistency in defining sub-groups in endurance running. Variables such as VO_2max values, running economy (steady-state oxygen consumption at a given running velocity) values (Barnes and Kilding, 2015), training distance, training experience and race results have been used to attempt to classify runners into sub-groups. To date no single consensus for a definition has been reached.

Scheer et al, (2018) define highly trained runners as those participating at a high level in local and regional competitions, but not part of a national team. The average weekly training distance of highly trained runners is 80 ± 27km, completed with 5.5, ± 1.2 days per week and who have participated in the sport for 9.4 ± 5.5 years (Scheer et al, 2018). The variability in this description alone is quite large, which can make it difficult to define the training status of a runner. The definition of a recreational runner is contrasting with some researchers defining this group as athletes who choose to run for non-competitive reasons such as goal achievement, health, affiliation and self-esteem (Masters, Ogles and Jolton, 1993). An alternative description of recreational runners by Buman et al, (2008) describes them as having had completed at least one marathon and had not qualified for champion classification (which are the top 10 runners, based on age adjusted finishing times for males and females). In addition, the runners in the aforementioned study reported the average marathon finishing times as 3.85 hours for the men and 4.55 hours for the women respectively (Buman et al, 2008).

The definition of an elite athlete is difficult to determine. Basavarajaiah et al, (2008, p.2257) defined elite athletes as “individuals who underwent organized training and participated in a team or individual sport at a national level”. A typical physiological indicator of elite performance in comparison to recreational performance, is that elite endurance athletes consistently obtain better results in running economy (210 ± 12 mL/kg/km), anaerobic threshold (61-88% of VO_2max) and VO_2max (values ranging from 70 to 85 mL/kg/min for elite marathon runners) (Lorenz et al, 2013). There is however a lack of consensus on what variables should be considered indicators of elite performance and/or if they should be considered in combination (Billat and Koralsztein, 2001).

It is known that the training status of a runner has a direct impact on their running kinematics. In a shod condition, Francis et al, (2016) found that high level runners had a shorter stride length than inexperienced runners. This means that highly trained runners are less likely to overstride, which can affect weight acceptance during the gait cycle and can result in excessive breaking forces, increasing the metabolic cost of running. When running with a shorter stride length, a runner's heel is located more underneath the centre of mass (COM), which can reduce hip and knee flexion (Francis et al, 2016). These adjustments could be attributed to a process called *self-optimisation* where runners select an optimal stride frequency to minimize energetic cost (de Ruiter et al, 2013). Research indicates that novice runners are more likely to run at sub-optimal stride frequency due to a lack of experience, more often than experienced runners would (Cavanagh & Williams, 1982; de Ruiter et al, 2013).

In a study on the physical and training characteristics of top-class marathon runners, the criteria to participate was determined by previous marathon performance (≤2h12min for men and ≤2h31min for women) the top-class marathon runners trained at least 10-14 times a week (±180-206km), whereas high level athletes trained 8-13 times a week (±140-168km) (Billat et al, 2001). The result of this study revealed that top-class (TC) marathon runners had a higher VO_2max than high level athletes (79.6 ± 6.2 vs 67.1 ± 8.1 mL·kg^{-1}, p=0.04). Furthermore, the TC marathon runners were less economical due to their higher marathon velocity (210 ± 12 vs 195 ± 4 mL·kg^{-1}, p = 0.009)."Energy cost of running was, therefore, not significantly correlated with marathon performance time (r = -0.44, p = 0.21)" (Billat et al, 2001, p. 2091).

Specific performance indicators such as VO_2max, lactate threshold and running economy are widely researched in the sport of road or 'flat' running. These multiple levels of variables attest to the complexity of defining an elite athlete. Performance indicators for trail running are not yet established as they are in road running, especially in terms of partitioning different levels of performance (Björklund, Swarén, Born and Stöggel, 2019).

2.5 RUNNING ECONOMY AND KINEMATICS

Various physiological determinants play a role in determining running performance. These determinants include VO_2max, lactate threshold (LT) and running economy (RE) and these values tend to differ substantially between elite, trained and untrained runners (Moore et al, 2016). Running economy is the rate of oxygen consumed at a given submaximal running velocity (Moore et al, 2016). Previous research suggests that a person's running biomechanics is one of several factors that can influence their RE (Moore et al, 2016; Saunders, Pyne, Telford and Hawley, 2017).

Moore (2017) examined the biomechanical factors that may affect RE. These factors were placed into two categories intrinsic (internal) and extrinsic (external). Intrinsic factors include a person's running biomechanics whereas extrinsic factors would include variables such as running surface and the effect that different shoes/footwear would have on running mechanics. Results from the research by Moore (2017) indicates that trained runners will self-optimize their running mechanics to suit their physiological state better than novice runners are able to. More specifically, the results indicated that the difference between preferred and optimal stride frequency is greater for novice than trained runners (8 vs 3%).

Various kinematic factors have been shown as being associated with better RE. Tartaruga et al, (2012) found that changes in running technique had an influence on RE and lead to improved running performance. Significant correlations between RE and biomechanical variables (vertical oscillation of the centre of mass, stride frequency, stride length, balance time, relative stride length, range of elbow motion, internal knee and angles at foot strike) were found. Other researchers (Martens et al, 2018; Moore et al, 2016) have confirmed the association between some kinematic factors and better RE, namely: greater knee flexion during stance, greater ankle dorsiflexion during stance, reduced knee range of motion during stance, as well as less ankle plantar flexion or less knee extension at toe off. Unfortunately, most of this research is based on road running, whereas similar data on trail running is lacking.

Studies have shown that runners adjust their running biomechanics to suit the surface changes they are confronted with (Voloshina and Ferris 2015), however there has been less research to indicate whether this same adjustment takes place when runners are confronted with conditions of fatigue.

A commonly investigated element of running kinematics is foot-strike pattern and its influence on running economy and performance. Multiple studies have investigated the kinetic and kinematic differences between a rear foot strike (RFS), mid-foot strike (MFS) and a fore-foot strike (FFS) and the influence thereof on running performance (Giandolini et al, 2014). Hasegawa, Yamauchi and Kraemer (2007) found that the faster runners, namely those who performed better in a marathon (42.2km) race, tend to avoid heel striking, rather running with MFS or FFS pattern. The belief is that those runners have a better running economy than those who run more slowly, with a RFS. However, some research indicates that 80% of runners have a RFS during a marathon and 74% in a half marathon, as their preferred way or running, despite the lower average speeds associated with RFS (Larson et al, 2011). Due to the controversial results, there is a theory that foot strike pattern is an element of running locomotion that adapts to suit each athlete over time, and that it is a highly individualized element of running gait and it should, potentially, not be modified. There is inconsistency in the relationship between performance and FSP in road running. It is not yet known whether the same applies to trail kinematics as a whole, whether this element of running kinematics should be modified and if it changes in FSP would have an effect on other kinematics such as AF.

2.6 RUNNING KINETICS AND KINEMATICS

Running performance is a complex phenomenon previously thought to be predicted largely by the "classic endurance model" (McLaughlin et al, 2007, p. 992), consisting of; VO_2max, LT and RE. Recently, this performance model has been criticized for its bias towards the physiological components of running performance (Vanrenterghem, Nedergaard, Robinson and Drust 2017). It has been suggested that the previously neglected biomechanical related factors may play a larger role in the variation of running performance, specifically amongst trail runners, than previously thought (Scheer, Ramme, Reinsberger and Heitkamp, 2015). The aforementioned biomechanical factors relating to human locomotion include both kinetics and kinematics (refer to Figure 2.2). For example, the average stride length (two steps) for highly trained runners was shown to be 4.5cm longer than in recreational runners (Bonacci et al, 2013). In addition, when running at slower speeds, highly trained runners tend to maintain a constant stride length as opposed to recreational runners who significantly change their running kinematics by drastically increasing/decreasing their stride length.

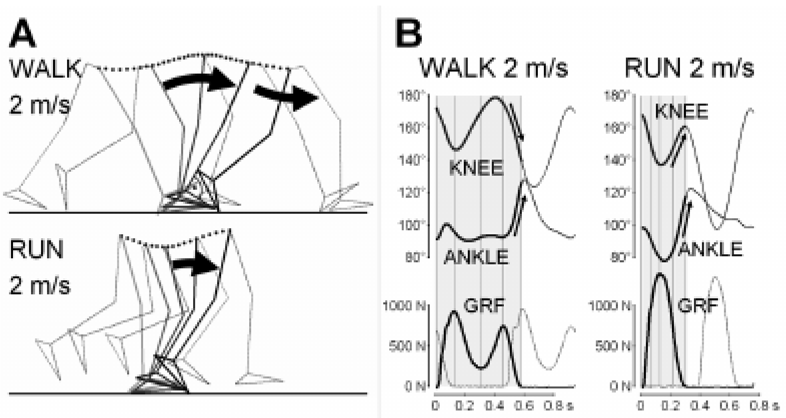

Figure 2.2. Illustration of both kinetic forces and kinematics from walking to running (Scheer et al, 2015) with permission from Thieme (Appendix F).

In road running, if a runner wants to increase their speed they typically increase their stride length however in trail running, the runner needs to consider the various types of gradient and terrain before making stride adaptations (Björkland et al, 2019). This is due to the challenging terrain that is usually experienced when runners trail run. The technical tracks with steep and ever-changing gradients can make stride adaptations more difficult to identify than they would be on a flat, even surface.

2.7 EFFECTS OF FATIGUE ON RUNNING KINEMATICS

Defining fatigue is a difficult task, with various definitions for acute, chronic, mental and physical fatigue. For the context of this study, researchers looked at physical fatigue which had to do with the performance of the motor system. Although Wan, Qin, Wang, Sun and Liu (2017, p.1) defined muscle fatigue, namely, "a decrease in maximal force of power production in response to contractile activity", the definition seems to be applicable to the current study, where athletic performance is limited and it can result in the inability to maintain strenuous or prolonged activity (Wan et al, 2017).

The complexity of determining distance running performance is described by Smoliga, et al, (2009, p.5) when they write: "Distance running performance is dependent on the integration of complex mechanisms of neuromuscular control, central and peripheral cardiovascular performance and fatigue resistance. The end results of these interactions is movement, as defined by running mechanics". The repetitive nature of running as a cyclical load is what adds to the feeling and effect of fatigue over time in the course of a run. As runners fatigue, their tolerance to manage these repetitive loads decreases and there is a breakdown in running gait kinematics as a result (Dierks et al, 2010). Giandolini et al, (2016) confirmed that the fatigue-related neurophysiological and biomechanical changes associated with prolonged graded running, as experienced in trail running, are different from those observed in level running. In terms of distance trail running, there is little research to indicate the effects of fatigue on running gait kinematics, and the extent of these difference between recreational and highly trained runners.

Table 2.1 Summary of studies, since 2004, applying fatigue protocols where its effect on running gait kinematics were measured.

Authors	**Environment**	**Surface**	**Duration/Distance**	**Training Status**
Hayes *et al*, 2004	“indoor”	“treadmill”	Run to exhaustion at vVO2max”	“6 sub-elite male middle distance runners”
Smoliga *et al*, 2009	“indoor”	“treadmill”	Exhaustive 5km run	“15 trained male distance runners”
Easthope *et al*, 2012	“mountain trail”	“undulating route, extensive uphill and downhill segment, rocky and technical”	15.6 km Time Trial	"experienced trail runners”
Kolblbauer *et al*, 2012	-	“treadmill”	Fatigue protocol	“novice runners”
Garcia-Perez *et al*, 2014	-	"track surface”	Test to exhaustion	"recreational runners”
Giandolini *et al*, 2016	Ultra Marathon	“large positive and negative elevations”	110km Ultra Trail Marathon	"well trained runners”
Maas *et al*, 2017	-	“track surface	Time trail (3200m) and exhaustive treadmill run	“novice and competitive runners”

Maas et al, (2018) investigated whether novice runners show greater changes in kinematics with fatigue compared with competitive runners. They hypothesized that changes in running gait kinematics may be more prominent amongst novice or recreational runners than elite runners due to difference in training status, experience and lack of technical skills to maintain their running gait kinematics despite the onset of fatigue (Maas et al, 2018). They found that novice runners experienced an increase in peak forward trunk lean, increased ankle plantar flexion and decreased knee flexion at the end of the exhaustive run whereas elite runners maintained the same trunk position and experienced less leg extension as a result of fatigue.

Gazeau et al, (1997) found that those runners exhibiting the most stable running styles were able to run for the longest. This was found specifically in the ability of the knee flexors to endure braking forces despite the onset of fatigue, which in turn, is a key for maintaining stride mechanics. This research was completed on long distance track athletes (800, 1500m and 3km runners). Hayes et al, (2004) found that athletes with better local muscular endurance would exhibited smaller changes in the kinematic variables observed. The strong negative relationships that were found between measure of local muscular endurance and kinematic changes support our hypothesis, where highly trained runners exhibited smaller changes in kinematic variables (Hayes, Bowen and Davies, 2004).

Koblbauer et al, (2014) suggested that fatigue may increase the chance of injury in recreational runners due to the effect that is has on lower limb kinematics. Koblbauer et al, (2014) used a steady state running-induced fatigue protocol and measured the changes between pre- and post-fatigued kinematics values which were compared and analysed using student t-tests. One of the many findings of this study were the changes in trunk kinematics, with peak trunk flexion increasing by four degrees in a fatigued state. The above-mentioned research on the effects of fatigue on running gait kinematics can prove to be useful as a tool for identification and appropriate correction of deterioration in a runners' technique (Elliot and Ackland, 1981). The effects of fatigue on kinematics has not been assessed in a trail running specific environment, such as a trail specific VO_2max lab test.

2.7 SUMMARY

Trail running gait kinematics are different to those of road running due to greater variations in terrain, gradient, surface and incline (Ehström et al, 2017; Scheer 2018). The running kinematics required to run with reduced metabolic cost (Voloshina and Ferris, 2015) and increased efficiency (Novacheck, 1998) are well researched, as well as the performance indicators for flat surface running and performance. However, the same cannot be said for trail running kinematic and performance prediction.

Analysing the difference in running gait kinematics for highly trained and recreational trail runners when under the influence of fatigue will provide a better understand of how gait kinematics change over time when a fatigue stimulus is present and if there are any significant differences between the responses of highly trained and recreational trail runners.

CHAPTER THREE – METHODOLOGY

3.1 INTRODUCTION

Research on running over the years has covered a multitude of topics. However, there is little research available that includes both recreational and highly trained trail runners in one study, specifically in terms of the differences in kinematics between recreational and highly trained trail runners. In this chapter there will be an overview of the study design followed by details about the participants, recruitment methods and inclusion and exclusion criteria. Following this, an outline of the study, the timeline that was used for the participants testing, an explanation of the specific equipment used in the laboratory, as well as data collection procedures is given.

Throughout this chapter there will be a reference to a "research team". This team consisted of three Master's students who conducted their research at the same time but with the goal of answering separate research questions. The primary researcher is Emily J. Robertson, with Matthew Swart and Oloff Bergh making up the rest of the team. The above-mentioned researchers form part of a greater team on the USTARR (University of Stellenbosch Trail and Road Running Research) project.

3.2 STUDY DESIGN

This study followed an experimental study design whereby stride length, stride frequency, forward trunk inclination (FTI), as well as angles of the ankle, knee, and pelvis were measured at foot contact, before and after a fatigue stimulus. VO_2max values results were observed and recorded for descriptive purposes, with no intervention.

3.3 PARTICIPANTS

Ten male recreational trail runners aged between 22 and 37 years (mean age 24.8 ± 2.4; body mass (kg) 78.0 ± 5.1; height (cm) 183.5 ± 6.8) and seven male highly trained trail runners aged between 26 and 37 years (mean age 35.0 ± 2.2; body mass (kg) 69.5 ± 4.3; height (cm) 177.5 ± 5.8) volunteered to participate in this study.

A priori power analysis was done α= 0.05, Power (1-β)=0.95 and effect size = 1.05. The effect size and power were determined based on the findings of Scheer et al, (2018) and Doma, Deakin and Sealey (2011) who used a similar exhaustive protocol. Calculations were done using G* Power™ (3.1.9.2) statistical software, as it has been shown to be appropriate for use in the social, behavioural and biomedical sciences (Faul, Erdfelder, Lang and Buchner, 2007). Out of all the runners who were interested in the study, two of them were excluded. One runner withdrew from the study due to time constraints and another due to injury.

3.3.1 RECRUITMENT METHODS

Purposive snowball sampling method was used to recruit the recreational participants. This was done due to the researcher's access to various groups of trail runners by association. A flyer (Appendix B) was created and distributed on social media (Whatsapp™, Facebook™ and Instagram™) as well as on notice boards around the Stellenbosch University campus. This type of distribution allowed for a diverse group of runners to be reached, varying in age and location. Individuals who made contact with one of the researchers and who met the inclusion and exclusion criteria of the study were asked to participate in the study.

Purposive sampling was used in order to recruit the highly trained runners. Researchers reached out to them over social media with an explanation of the study. They were asked to respond with their e-mail address if they were interested in participation so that the project information and informed consent forms (ICF) could be sent to them.

3.3.2 INCLUSION CRITERIA

To be included in the study, the participant needed to be a male trail runner (Ferber, McClay and Williams, 2013; Chumanov, Wall-Scheffler and Heiderscheit, 2008), between the age of 18 and 40 years old. Participants needed to be willing to participate in both the VO_2max as well as time-to-exhaustion tests. Completing and signing an informed consent form (Appendix C) was a requirement before the testing process began.

Recreational participants were included if they ran for non-competitive reasons (e.g. goal achievement, health, affiliation and self-esteem), their self-reported weekly mileage was between 16-24km (Ordendurff et al, 2018), or if they had completed a road running marathon but did not qualify for champion classification based on their age adjusted finishing times (Buman et al, 2008). Highly trained runners qualified for inclusion based on self-reported weekly training mileage of 80 ±27km per week, as well as being one of the top ten African finishers at UTCT (65 or 100km) in 2019.

3.3.3 EXCLUSION CRITERIA

Runners needed to be injury free (self-reported) for six months prior to testing, to avoid any unusual changes in running gait kinematics that could occur as a compensation for injury (Napier, Cochrane, Taunton and Hunt, 2015). Participants with gait or postural abnormalities that would influence running gait kinematics, such as prosthetics were excluded. If the participant chose to withdraw from the testing process at any moment, they were allowed to do so, and their data would be excluded from the study.

3.4 STUDY OVERVIEW

Once participants had responded to the flyer, showing interest in participating in the research or they responded to the message sent to them over social media, they were sent the ICF to read and complete over e-mail prior to their participation. The researcher then checked if they met the inclusion criteria before a booking for their testing session was made. All testing took place at Stellenbosch University, Department of Sport Science, and the CAF (Central Analytical Facilities) – Neuromechanics Laboratory (CAF Lab). If the participant had any questions or concerns, those were answered before testing began. If the participants refused to sign the ICF, they were excluded from the study with no further testing taking place.

Prior to testing, participants were sent a check list, asking them to wear their usual trail running shoes to the testing session, with loose fitting running shorts in order for Inertial Measurement Units to be placed comfortably directly on the skin. Once the participants signed the ICF, anthropometric measures were taken. Once these initial measurements were taken, ten IMU's were attached to the participant at various anatomical landmarks. The research team were familiar with this procedure as the same procedure was used during the proof of concept for the study. Additionally, all researchers had completed the CAF-Neuromechanics workshop and training in July 2019.

No payment for participation in this study was provided, however participants were sent a copy of their VO_2max report once their results had been processed. Participants were then allowed to request a free consultation of one hour with the investigators to discuss their data and results and how they might apply it to their current training and performance.

3.5 ETHICS

This study was approved by the Health Research Ethics Committee, Stellenbosch University (N19/07/078) (Appendix E). The study was conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, the South African Guidelines for Good Clinical Practice (2006), the Medical Research Council (MRC) Ethical Guidelines for Research (2002), and the Department of Health Ethics in Health Research: Principles, Processes and Studies (2015).

3.6 TEST AND MEASUREMENTS

Ensuring ecological validity within the scope of a masters study can be difficult to achieve due to time, budget, and resource constraints. Due to the aforementioned constraints, the decision was made to keep the testing indoors instead of on a trail surface due to lack of control of outdoor testing and the limitation of the technology in an outdoor setting. Specifically, the IMU’s presented limitations as they needed to be within 150m distance of the desktop at all times with a flat/level surface for calibration between trials, making outdoor testing difficult. Trying to create trail-specific interventions was challenging as simulating a trail run in a laboratory was not possible due to lack of specific terrain and grade variability (Easthope et al, 2014). Existing literature indicates that different running surfaces lead to changes in running patterns, however, it is accepted that treadmill running is also representative of overground running (Riley et al, 2008; Schache et al, 2001).

The reason for making use of the BERTEC treadmill was due to multiple methodological advantages, namely, high repeatability of trials, convenient instrumentation, control of the environment (laboratory temperature), and the ability to increase speed and incline by ramping the treadmill for ecological validity, as well as minimal space required (García-Pérez et al, 2014). Refer to Figure 3.3 for an example of the laboratory setup.

3.6.1 PROCEDURES PRIOR TO ARRIVAL

Prior to their arrival, participants received an email outlining the testing process for the day and what was expected of them.

Participants were sent the following checklist after confirming their testing date and time:

1. Refrain from any high intensity exercise 24 hours before their testing date
2. Not to eat within 2 hours of testing
3. Wear loose fitting running shorts (that IMU's can be placed under), no tights.
4. Wear trail running shoes.
5. Avoid excessive caffeine or alcohol consumption within 24 hours of testing.

The CAF lab, testing space and equipment was prepared prior to participant arrival to reduce the length of time the participants needed to be at the lab. These preparations included sterilizing the lab space, equipment, straps and mask as well as cutting the tape for the IMUs and calibrating the incline of the treadmill to zero degrees incline before the test began.

3.6.2 ANTHROPOMETRICS

Once participants had arrived, various anthropometrical measures were taken namely; height (cm) and weight (kg) for descriptive purposes. Weight was measured in kilograms using the OMRON scale (OMRON Healthcare Co., Ltd.. Netherlands) provided by the CAF lab. Participants removed their shoes and were asked to step onto the scale with their arms by their side, looking straight ahead. Weight (kg) was then recorded to two decimal places.

3.6.3 KINEMATIC DATA COLLECTION

Inertial measurement units (IMUs) (Noraxon myoMotion Research PRO IMU, Noraxon, USA) were used to collect the kinematic data, namely SL, SF (cadence), FTI and angles of the hip, knee and ankle at foot contact in the sagittal plane. IMU's have a triaxial accelerometer which measures acceleration continuously, close to the runner's centre of gravity. These devices are used regularly in gait analysis (Seel, Raisch, and Schauer 2014) and have been validated (De Pasquale and Somà, 2010) for running related research as they allow non-invasive measurements to be taken. Their wireless system allows an athlete to run without equipment interference. Direct evidence for the performance of the inertial sensor-based systems relative to that of conventional gait analysis in a motion laboratory was reviewed for the time period from 2005 to 2007 (Miller et al, 2019). Miller et al, (2019) reported that a total of 15 research articles were included in the systematic review and meta-analyses that compared gait parameters obtained using wearable or inertial sensors against those obtained using a motion laboratory. The results indicate that for gait speed, step length, step time and stride time there was a good level of agreement between wearable inertial sensors against those obtained using a motion laboratory (Miller et al, 2019). In the current study, the IMU weighed 20g, measuring at 100Hz and had significant battery life to record continuously throughout the duration of the testing process. A low-pass Butterworth filter with a cut-off frequency of 100 Hz was applied, and recorded signals were streamed to the Noraxon program on a computer in the lab. The software used to analyse these signals was Noraxon MR v 14.2. The placement of the IMUs were determined using the guidelines provided by the CAF lab as well as information gathered from previous research and methodologies (Maas et al, 2017; Seel et al, 2014; Strohrmann, Harms, Kappeler-Setz, and Troster, 2012). Information from all ten of the IMUs were used for final data processing.

The IMUs were attached to the participants', namely at: left and right feet feet (on top), shanks (lateral surface) and thighs (lateral surface) as well as lower, middle and upper thoracic spine (medial placement) (Rispens et al, 2014). The units were attached using double sided tape, then covered with adhesive tape to minimize movement and interference as the athletes sweated. The IMU's used for the pelvis, thigh and shank regions were placed in tight-fitting elastic straps that were fastened around the runners' limbs. Once all units were attached, streaming tests were done before the calibration of the units in order to prepare the Noraxon myMETRICS Lab software to collect data. Static calibration allowed the researchers to see if all the IMUs were online and if treadmill mode was working. The participant was asked to stand with their feet shoulder width apart, just behind the laboratory doors, facing the treadmill and the direction they were going to be running in. Once this was captured, a second dynamic calibration was done. This involved a series of movements to ensure that the IMUs were in the correct location and that they recorded movement in the correct plane. For example, if the left IMU was placed on the right foot, when the movement of the left foot occurred during dynamic calibration, the software recording the movements would indicate that there is an error and that the IMU is not in the correct location. These streaming tests were saved on the laboratory computer along with the rest of the data captured for each participant. Saving each test under specific file names helped to understand which variables were tested for each trial and to give order to the data collected. An example of a file name is as follows, “Participants_(1)_Dynamic_Calibration”.

Figure 3.1: Left: participant with all IMU’s attached, while completing the VO2max test. Right: Static calibration position as well as the static calibration position. A, B and C indicate IMU positioning on the runner. (Source: Emily Robertson)

3.6.4 MAXIMAL TESTING

Included in the ICF was a detailed description of the VO_2max and time-to-exhaustion (TTE) test, which, together with a break of ~5 min in between tests, were the components of the ‘fatigue protocol’. However, the process to complete each test was also verbally explained to each of the participants on the day of testing.

The protocol followed for the current study was inspired by the trail test completed in the study of Scheer et al, (2018) where VO_2max testing for trail runners was considered to investigate whether there is a specific exercise protocol for trail runners, as shown in Figure 3.2. Three test protocols were completed, “1) graded exercise test (step test): starting at 8.0 km/h, step duration of 3 min, increased by 2.0 km/h with standardized pause of 30 s after each step for capillary blood lactate (BLa) measurements, inclination 1.0 %; 2) incremental exercise test (ramp test): starting at 10.0 km/h, continuous increase by 1.0 km/h per minute, inclination 1.0 %; 3) trail test: starting at 10.0 km/h, continuous increase by 0.5 km/h per minute and continuous inclination increase by 1.0 % per minute starting at 0.5 %.” (Scheer et al, 2018, p. 457).

During their laboratory visit, each participant began with a VO_2max test. This test involved a warm-up of easy jogging at 8.0km/h for five minutes, based on the protocol of Scheer et al. (2018). Immediately following the warm-up the VO_2max test began at 10.0km/h, with a continuous increase of +1.0km/h per minute and continuous increase of inclination by 0.5% per minute starting at 0.0%. The participants were verbally encouraged during the test to run for the longest time possible until volitional exhaustion was reached.

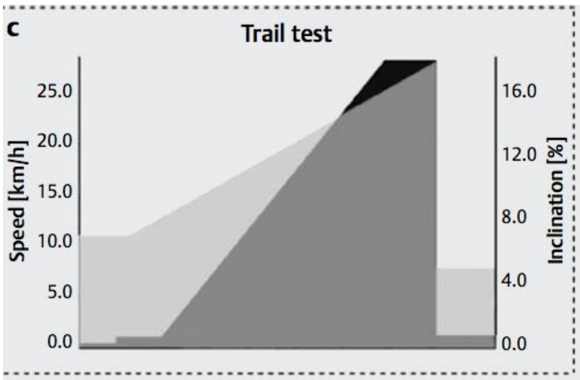

Figure 3.2. Illustrates the trail specific fatigue test, showing the increase in speed (km/h) and inclination (%) (Scheer et al., 2018, p. 457) with permission from Thieme (Appendix F).

Following the VO_2max, participants had a five-minute break in which the treadmill incline was adjusted and the oxygen mask removed. IMUs were recalibrated and immediately after this, the TTE test began. The finishing speed and gradient of each participants VO2max test were the values used for establishing the speed and gradient for the TTE test (Robinson, Graham and Headley, 2004). Each participant began their time-to-exhaustion (TTE) test at an individualized speed and gradient, equal to 87.5% of the finishing speed and gradient of their VO_2max test. Once the speed and gradient were set, they remained unchanged throughout the duration of the test. Participants ran until volitional exhaustion was reached.

It was suggested that running at incline on a treadmill better replicates training and racing environment for trail running participants in comparison to level running (Scheer et al., 2018). The results of this adapted VO_2max test indicated that trail runners perform better on the VO_2max at incline rather than level running (Scheer at al., 2018). This could be due to the specific adaptations that trail runners have developed to incline running.

The criteria used for the determination of a valid VO_2max test were a plateau in VO_2, a ≥9 score for rate of perceived exertion on the BORG-10 scale (RPE), respiratory exchange ratio (RER) of 1.1, and a heart rate (HR) within 10 beats of the age-predicted maximum value (220 – age) (Easthope et al, 2010).

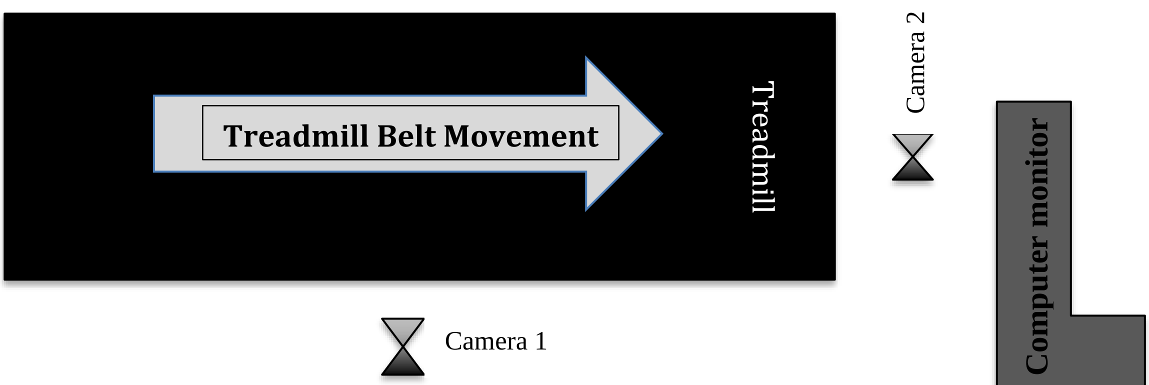

Figure 3.3 – Schematic of Laboratory System Setup

3.6.5 POST TESTING

Once the participants had completed the TTE test, the treadmill was stopped, ending the test. The participant was given a few minutes to recover and drink some water. IMU's were removed and placed back into their charging cradle. Participants left the lab and their VO_2max reports were sent to them via email the following day. The researchers then cleaned the lab and sterilized all the equipment in preparation for the next test.

3.7 DATA ANALYSES

All data that was gathered from the participant was recorded and saved in Noraxon on the laboratory computer. The researchers were given access to all of this data in order to go through each trial and ensure there were no recording errors and that dynamic calibration before the test was successful. If it was not successful, manual corrections needed to be done on the data before the processing could begin.

During this manual processing phase, specific data filtering was done in order to ensure specific markers were in place. This involved dropping markers at the start and end of each trial to ensure the videos of the participants were matched with their specific IMU data. This helped to determine if any recording or data collection errors had taken place. Once this process was completed, the edited data was handed back to the Neuromechanics lab and their technicians for data processing to take place.

3.8 STATISTICAL ANALYSES

The Division of Epidemiology and Biostatistics at the Faculty of Medicine and Health Science, Stellenbosch University were consulted regarding the statistical analyses required. All statistical tests were analysed using IBM SPSS Statistics 27.0 (SPSS Inc., Armonk, New York, USA). The Shapiro Wilks test was used to assess for data normality, as seen in previous research (Maas et al, 2017; Scheer et al, 2020). This test is suitable for smaller sample sizes <50. If the significance value of the Shapiro-Wilkes test is ≥ 0.05 the data is normally distributed. The data was found to be normally distributed, therefore standard parametric tests, namely the paired student t-test was used to determine if significant differences were present at the beginning and the end of the adapted trail VO_2max test) between the kinematic variables as well as independent t tests to determine if there were significant differences between recreational and highly trained participants pre and post adapted trail VO_2max test.

A one way repeated measures ANCOVA was completed in order to compare the differences between the highly trained and recreational runners at the beginning, middle and end of the run to exhaustion, while controlling for treadmill speed and incline at the end of the VO_2max test. The partial Eta squared were used to determine effect sizes, which were interpreted as follows, $\eta_p^2 = 0.01$ is a small effect, $\eta_p^2 = 0.06$ is a medium effect and $\eta_p^2 = 0.14$ is a large effect. Statistical significance was accepted when $p < 0.05$ for all tests.

CHAPTER FOUR – RESEARCH ARTICLE

Changes in running gait kinematics of highly trained and recreational trail runners during an adapted trail running VO_2max test

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This article has been submitted to the journal Gait & Posture. This article is included herewith in accordance with the guidelines for authors of this journal (Appendix A). This does not imply that the article has been accepted or will be accepted in the said journal. As a result, the referencing style may differ from other chapters of the thesis. The co-authors of the article, Prof Ranel Venter (study leader) and Mr Simon De Waal (co-study leader) hereby give permission to the candidate, Emily Robertson, to include the article in this thesis.

CHANGES IN RUNNING GAIT KINEMATICS OF HIGHLY TRAINED AND RECREATIONAL TRAIL RUNNERS DURING AN ADAPTED TRAIL RUNNING VO_2MAX TEST

Emily J. Robertson [a], Simon J. de Waal [a], Ranel Venter [a]

[a] Department of Sport Science, Faculty of Medicine and Health Science, Stellenbosch University, Stellenbosch, Western Cape, South Africa

19166443@sun.ac.za ; simondw@sun.ac.za ; rev@sun.ac.za

Corresponding Author:

Emily Jeanne Robertson

+27 72 261 5045; emrobertson97@gmail.com

Tassenwyk, Marais Street, Stellenbosch, 7600, Western Cape, South Africa

ABSTRACT

Background The influence of fatigue on running gait kinematics are not well documented in the trail running population, specifically between highly trained and recreational groups. Previous research on running gait kinematics has largely focused on road runners, and relationships between kinematics, performance, injury and fatigue, to name a few, has been established in this population. There is limited research on trail running gait kinematics available and the role thereof in trail running performance and training, in comparison to road running. Differences in trail running kinematics between recreational and highly trained trail runners specifically have not been researched to the same extent as road running kinematics. *Research Question* The purpose of this study was to compare running gait kinematics between a highly trained (n=7) and recreational (n=10) group of trail runners after an adapted trail running VO_2max test. *Methods* Seventeen runners, age 22-37 completed an indoor maximal treadmill running protocol to volitional exhaustion. Select running gait kinematics included stride length, stride frequency, ankle angle at contact, knee flexion, hip flexion and forward trunk inclination were measured by inertial measurement units (IMU) (100Hz). Running gait kinematics from the last ten seconds of the corresponding minute, the start (0%), middle (50%) and end (100%) of each individual's VO_2max test were analyzed. *Results* When analyzing the changes in kinematics at the start of the VO_2max test there were no significant differences found between the groups in a non-fatigued state, during submaximal running (10km/h). Results from the end of the VO_2max test indicated that there were no significant differences between the groups for step cadence (SC), ankle dorsiflexion (ADF), hip flexion (HF) and forward trunk inclination (FTI). However, significant differences were observed for SL (HT: 2.57 ± 0.28; REC: 2.95 ± 0.23, $p < 0.01$) and KF (HT: 23.20 ± 5.90; REC: 29.95 ± 4.21, $p < 0.05$) at the end of the VO_2max test. Results from a repeated measures ANCOVA (controlling for incline and speed of the treadmill) indicated that running gait kinematics changed in a similar manner for both groups under various conditions of fatigue. Although no statistical significance was shown, medium – large effect sizes illustrate that there was a trend of kinematic change over time and between groups that could

be shown with a larger group of participants. *Significance* These results can help to further understanding of the relationship between running gait kinematics, training status and fatigue.

Keywords: Trail running, kinematics, treadmill, fatigue, VO_2max

INTRODUCTION

Trail running, compared to road running, poses unique physical challenges for an athlete due to the types of terrain a runner needs to navigate, which include a variety of different surfaces and significant vertical elevation gain [1]. Successive bouts of uphill and downhill running throughout the race, result in major physiological and mechanical changes for the runners [2] with the state of fatigue differing from one runner to the next [3]. Previous research indicates that surface changes are linked to an increased variability in running gait kinematics, which are not present when running on smooth, flat terrain (4).

Different kinematic profiles exist for trail and road running based on differences in terrain, gradient and physical demands. Kinematics such as vertical oscillation [5], ground contact time [6], foot strike pattern [7] and leg clearance [8] are significantly different in trail running when compared to road running. In trail running, the dynamic and undulating surfaces [9] affect the consistency in kinematics such as step length in comparison to running on an unchanging surface such as the road. Step width and length of runners can increase by up to five percent when running on uneven as opposed to smooth terrain [7]. In road running, lower vertical oscillation, greater leg stiffness, less leg extension at toe off, larger stride angles and maintenance of arm swing are common for better performance, despite the onset of fatigue [5]. It is known that kinematics are affected by the onset of fatigue, such as the documented increase in foot angle at contact and stride length in road runners [10], however in trail runners this has not yet been established. There is limited research into preferred kinematics for trail runners and the influence of fatigue on their running gait kinematics. The latter point is especially important since it is known that the fatigue status, and therefore the performance, of a trail runner changes throughout the course of a race [11].

Training status has a direct influence on running gait kinematics, with noticeable differences between recreational runners and highly trained runners [12]. Previous research on road runners indicates that well trained runners are more resistant to the onset of fatigue and the resulting kinematic changes [10] than their recreational counterparts due to better training status [4] and experience [13]. This idea is supported by results from research by Maas et al, (2017) where novice runners had a greater increase in forward trunk lean at the end of an exhaustive run in comparison to competitive runners. Furthermore, highly trained road runners are reported to have significantly longer stride length than recreational road runners which may favourably influence factors such as running economy and race performance [14, 15]. Additionally, when running at submaximal speeds, highly trained road runners tend to maintain a constant stride length, while recreational runners demonstrate significant variability in their stride length [5]. However, it is not yet known if the same is true for recreational and well-trained trail runners.

Research on running retraining has demonstrated favorable outcomes for modifying biomechanical risk factors associated with running-related injuries [16]. However, minimal evidence to guide these modifications exists and it is not yet known whether these changes will improve running kinematics in highly trained and recreational trail runners. Despite success with gait modifications and retraining, some research has indicated that these effects are only short term. It has been shown that runners who have been through the gait modification process will over time, revert to their original running gait, with fatigue being one of the main influences for this reversion. More specifically, foot strike kinematics tend to be maintained despite the influence of fatigue but most changes to stride length and frequency only have short term results [17].

Popularity of trail running is increasing, without research into what constitutes favorable running kinematics for trail runners. It is not yet known if there are significant differences in running gait kinematics between well trained and recreational trail runners, and what the effect of fatigue is on trail runners' kinematics. Knowledge of these differences could assist with evidence-based training programs and provide guidelines for recreational trail runners to improve their kinematics and subsequently their performance. Therefore, the purpose of this study was to compare the differences in running gait kinematics between highly trained and recreational trail runners after an adapted, fatigue inducing, trail running specific VO_2max test.

METHODS

Ten male recreational trail runners aged between 22 to 27 years (mean age 24.8 ± 2.4; body mass (kg) 78.0 ± 5.1; height (cm) 183.5 ± 6.8) and seven male highly trained trail runners aged between 26 and 37 years (mean age 35 ± 2.2; body mass (kg) 69.5 ± 4.3; height (cm) 177.5 ± 5.8) volunteered to participate in this study. Recreational participants were included in the study if; they ran for noncompetitive reasons (goal achievement, health, affiliation, and self-esteem), their self-reported weekly mileage was between 16-24km [18], or if they had completed a road running marathon but did not qualify for champion classification based on age adjusted finishing times [18]. A priori power analysis was done with $\alpha = 0.05$, Power $(1-\beta) = 0.95$ and effect size = 1.05 used to determine sample size [19]. Adequate sample size was calculated based on the findings of Scheer et al, (2018) and Doma et al, (2011) who used a similar exhaustive protocol. Following the study, a post hoc analysis was completed which indicated that 12 participant's data would influence the statistical power (Power$(1-\beta)$) of the study to 0.98 (n = 12).

Runners needed to be injury free (self-reported) for six months prior to the study, to avoid any unusual changes in running gait kinematics that could occur as compensation for injury [17]. Runners with gait or postural abnormalities that would influence running gait kinematics, such as prosthetics were excluded. Highly trained runners qualified for inclusion based on their self-reported weekly training mileage (minimum of 80 ± 27 km [12]), as well as finishing amongst the top ten African runners during the International Ultra Trail Cape Town trail running race (100km/65km events) in 2019. The purpose of a smaller sample size for the highly trained group is due to access and statistical power; it is hypothesized that their effect size (ES=0.65) will be greater than the recreational runners [19].

STATISTICAL ANALYSIS

Statistical tests were completed using IBM SPSS Statistics 27.0 (SPSS Inc., Armonk, New York, USA). The Shapiro-Wilke test was used to test for normality (Maas et al, 2017 & Scheer et al, 2020). All data was found to be normally distributed, therefore standard parametric tests were conducted to answer the research questions of the study. A paired t-test was conducted to measure the difference in all running gait kinematics for the entire sample (n=17) from time point 1 (beginning of the adapted VO_2max test) to time point 3 (end of the VO_2max test). Cohen's D was used to determine effect sizes, which were interpreted as follows, d = 0.2 is a small effect, d = 0.5 is a medium effect and d = 0.8 is a large effect. Thereafter, an independent t-test was conducted to determine differences between groups (highly trained vs recreational) at time point 1 and 3 of the VO_2max test for all kinematic variables. Finally, a one-way repeated measures ANCOVA was conducted to compare the differences between the highly trained and recreational runners for all kinematic variables at (0%), 50% (middle), and 100% (end), of the VO_2max test. Treadmill speed and incline at the end of the VO_2max test were controlled for as covariates in the ANCOVA analysis. The partial Eta squared was used to determine effect sizes, which were interpreted as follows, $\eta_p^2 = 0.01$ is a small effect, $\eta_p^2 = 0.06$ is a medium effect and $\eta_p^2 = 0.14$ is a very large effect. Statistical significance was accepted when $p < 0.05$ for all tests.

MEASUREMENTS AND PROCEDURES

The VO_2max test involved a warm up of easy jogging at 8.0km/h for five minutes. Immediately following the warm up the VO_2max test began at 10.0km/h (0%, submaximal running), with a continuous increase of +1.0 km/h per minute and continuous inclination increase by 0.5% per minute starting at 0.0%. The participants were verbally encouraged during the test to run for the longest time possible until volitional exhaustion was reached.

Inertial measurements units (IMUs) (Noraxon myoMotion Research PRO IMU, Noraxon, USA) were used to record and stream kinematic data directly to Noraxon® myoRESEARCH software, on the laboratory computer. The unit attachments included: feet (on top), shanks (lateral surface) and thighs (lateral surface) as well as lower, middle and upper thoracic spine (medial placement). Two NORAXON NiNOX™ (USA) cameras were also set up in, one meter behind the treadmill and another 0.5m on the side of the treadmill, in order to have video recordings of the testing process.

The IMUs were attached to the participants' feet and thoracic regions using double sided tape, then covered with adhesive tape to minimize movement and interference as the athletes sweated. The IMUs used for the pelvis, thigh and shank regions were placed in elastic straps that were fastened around the runners' limbs. Once all units were attached, streaming tests were completed before calibration of the units in order to prepare the Noraxon myMETRICS Lab software to collect data. These streaming tests were saved on the laboratory computer along with the rest of the data captured for each participant.

For the VO_2max test, the start of the test was seen as (0%) where all runners began at submaximal speed (10km/h), the middle at 50% and the end at 100% of the test. Data was recorded for 10 consecutive seconds at the end of each minute at three time points during the VO_2max test.

RESULTS

When comparing the running gait kinematics between submaximal running (pre fatigue) and maximal running (fatigue), several statistically significant differences and large to very large effect sizes were observed for the whole group (n = 17) (See Table 4.1).

When comparing the whole group (n = 17) from the start of the VO_2max test to the end, significant differences ($p < 0.05$) were found for step cadence (SC) (*d* = -3.16, large effect) stride length (SL) (*d* = -0.42, moderate effect), ankle dorsiflexion (ADF) at contact (*d* = 0.65, moderate effect), knee flexion angle at contact (*d* = -2.26, large effect), hip flexion at contact (HF) (*d* = -3.34, large effect) and forward trunk inclination at contact (FTI) (*d* = -0.36, small effect) (see Table 4.1).

Table 4.1. Difference in kinematic variables and adapted VO_2max test performance for the whole group and within groups at the beginning and end of an adapted VO_2max test. Associated *p*-values are reported for the test.

Variable	**Pre (Mean ±SD)**			**Post (Mean ± SD)**			**Pairwise Comparison Effect Sizes (ES) for the Group. (r^2)**
Groups	**Rec (n=10)**	**HT (n=7)**	**Group (n=17)**	**Rec (n=10)**	**HT (n=7)**	**Group (n=17)**	**Group (n = 17)**
Step Cadence (steps/min)	167 ±4.98	170.70 ±10.67	169.18 ±8.77	186.71 ±3.15	188.30 ±14.59	187.65 ±11.14 #	-3.16 (very large)
Stride Length (meters)	2.67 ±0.37	2.51 ± 0.34	2.58 ± 0.35	2.95 ±0.23	2.57 ± 0.28*	2.73 ± 0.32	-0.42 (medium)
Ankle Dorsiflexion (°)	-2.85 ±7.70	-7.47± 7.27	-4.75 +_7.66	-8.25 ±6.16	-7.68 ±5.41	-8.02±5.69 #	0.65 (large)
Knee Flexion (°)	18.10 ±6.27	12.14 ±3.73*	14.59 ±5.63	29.95 ±4.21	23.20 ±5.90*	25.98 ±6.16 #	-2.26 (very large)
Hip Flexion (°)	19.91 ± 7.38	19.65 ± 3.57	19.76 ± 5.25	36.10 ± 8.04	32.78 ±4.19	34.14 ± 6.08 #	-3.34 (very large)
Forward Trunk Inclination (°)	22.01 ±6.58	18.60 ±4.49	20.0 ±5.53	22.70 ±5.81	20.83 ±6.30	21.60 ±5.99	-0.36 (medium)

Table 4.2

Groups	Rec (n=10)	HT (n=7)	Group (n=17)	Rec (n=10)	HT (n=7)	Group (n=17)	Cohen's D effect sizes
VO_2max (ml.kg.min^{-1})	N/A	N/A	N/A	66.20 ±5.12	71.71. ± 6.18	68.47 ± 5.35	0.97 (large)
Time to Volitional Exhaustion	N/A	N/A	N/A	4.60 ±1.95	11.14 ±8.82		1.16 (very large)
Treadmill Speed (km/h)	8.0	8.0	8.0	16.56 ± 0.99*	17.71 ± 3.88*	17.03 ± 4.05	3.35 (very large)
Treadmill Incline (°)	0	0	0	3.8 ± 0.50*	5.0 ±1.23*	4.05 ± 0.55	1.15 (large)

All joint angles were measured at foot contact, (° = degrees).*P < 0.05 indicates a significant difference between recreational (Rec) and highly trained (HT) runners at either Pre or Post.** P < 0.01 between recreational and highly trained.# P < 0.05 indicates a significant difference for group between Pre and Post.

Differences between groups during submaximal and maximal running were compared, without controlling for incline and speed, to observe if there were differences seen in running gait kinematics. At the start of the VO_2max test, no significant differences were found between the groups in a pre-fatigued state for the following variables: Step cadence (SC) ($p = 0.41$) stride length (SL) ($p = 0.37$), ankle dorsiflexion (DF) at contact ($p = 0.23$), knee flexion at contact ($p = 0.05$) hip flexion at contact (HF) ($p = 0.93$) and forward trunk inclination at contact (FTI) ($p = 0.26$).

At the end (fatigued state) of the VO_2max test, no significant differences were found between the groups in a fatigued state for; step cadence ($p = 0.78$), ankle dorsiflexion at contact ($p = 0.84$), hip flexion at contact ($p = 0.34$) and forward trunk inclination at contact ($p = 0.54$). However significant differences were observed for stride length ($p < 0.01$) and knee flexion angle at contact at the end of the test ($p < 0.05$) (Table 4.1). Previous research has shown that "failure to maintain leg stiffness resulted in the early onset of changes in stride mechanics leading to reduced performance.” [28]. Derrick, Dereu and McLean (2002) observed a relationship between SL and leg stiffness, as stride length increased during an exhaustive run, the ability to maintain leg stiffness decreased. The recreational runners had a greater stride length and a knee flexion angle at the end of the VO_2max test (2.95m ± 0.23; 29.95 ± 4.21°) in comparison to the highly trained runners who had a smaller stride length and knee flexion angle at contact (2.57m ± 0.28; 23.20 ± 5.90°). These results were observed without controlling for incline and speed.

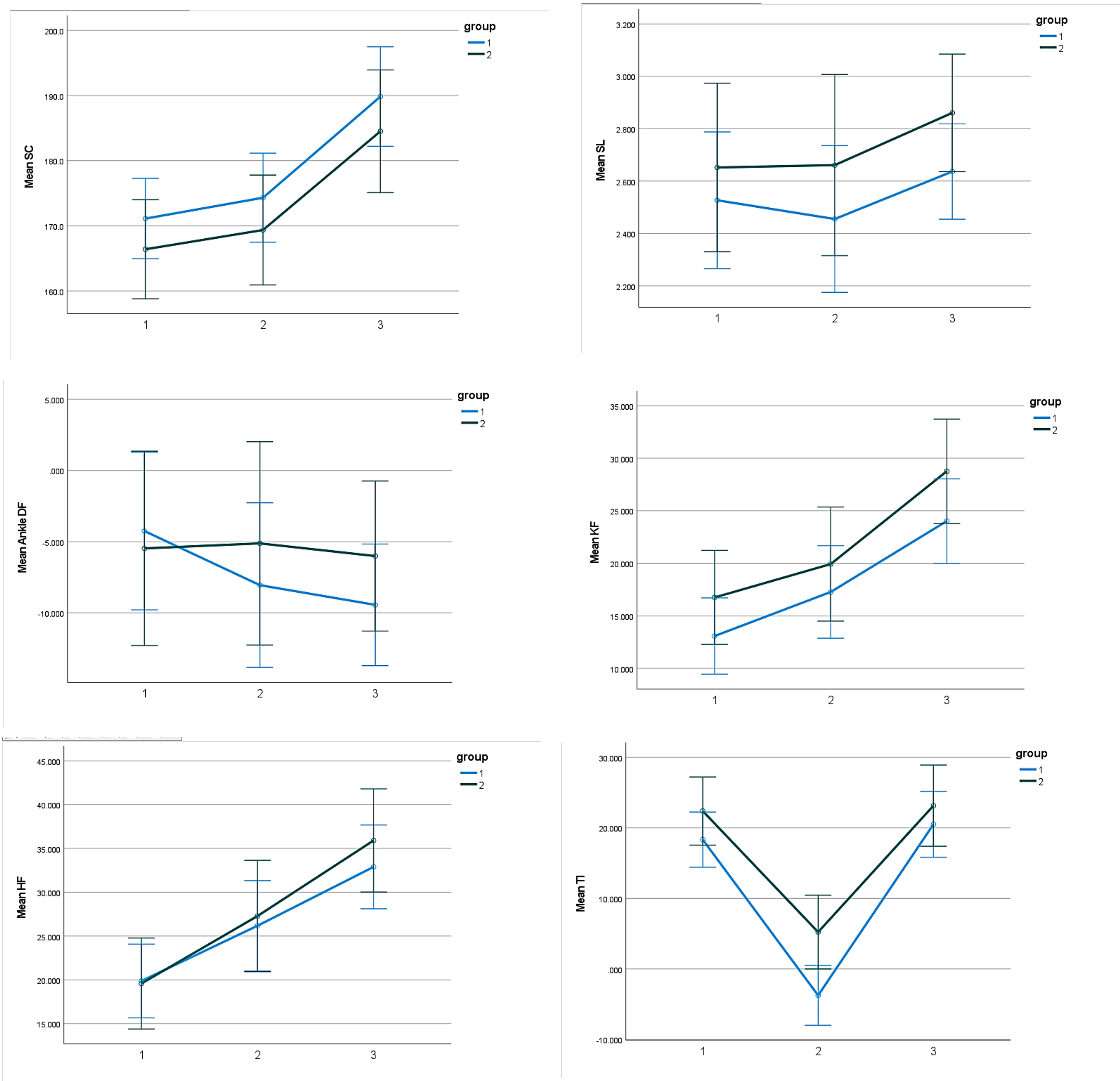
Average values for each of the variables (recreational; highly trained) are as follows: SL (2.64m ± 0.28; 2.34m ± 0.23), SC (177 ± 14.58 per minute; 188 ± 3.14 per minute), ADF (-2.19 ± 6.16 °; -2.39 ± 5.41°), KF (21.12 ± 5.89°; 14.78 ± 4.20°), HF (14.80 ± 4.19 °; 19.18 ± 8.04°) and TI (-5.40 ± 6.30°; -6.04 ± 5.81°).

A repeated measures ANCOVA was used to investigate the differences in running gait kinematics between recreational and highly trained groups at three time points (0%, 50%, 100%) of the VO_2max test. This analysis was done while controlling for speed and incline of the treadmill. No significant difference in step cadence was observed over time, however there was a large effect size ($p = 0.24$; $\eta_p^2 = 0.20$; $\Lambda = 0.24$). There was no significant difference for the group ($n = 17$) for stride length but there was a large effect size ($p = 0.09$; $\eta_p^2 = 0.33$; $\Lambda = 0.67$). ADF at contact showed no significant time effect but a medium effect size was present ($p = 0.61$; $\eta_p^2 = 0.07$; $\Lambda = 0.92$). Knee flexion showed no significant time effect but there was a medium effect size ($p = 0.68$; $\eta_p^2 = 0.06$; $\Lambda = 0.93$). Hip flexion at contact showed no significant time effect ($p = 0.90$; $\eta_p^2 = 0.01$; $\Lambda = 0.98$). The same applies for forward trunk inclination, no significant time effect was found however there was a large effect size ($p = 0.31$, $\eta_p^2 = 0.17$, $\Lambda = 0.82$).

In terms of a time*group interaction effect, no statistically significant interaction was found for: SC, SL and KF (SC: $p = 0.98$; $\eta_p^2 = 0.003$; $\Lambda = 0.99$; SL: $p = 0.88$; $\eta_p^2 = 0.02$; $\Lambda = 0.97$; KF: ($p = 0.71$; $\eta_p^2 = 0.05$; $\Lambda = 0.94$). ADF showed no significant time*group effect although there was a large effect size ($p = 0.26$; $\eta_p^2 = 0.20$; $\Lambda = 0.80$). HF and FTI both showed no significant time*group effect but both variables had a medium effect size (HF: $p = 0.48$; $\eta_p^2 = 0.11$; $\Lambda = 0.88$; FTI: $p = 0.45$; $\eta_p^2 = 0.12$; $\Lambda = 0.87$).

In terms of differences in gait kinematics between groups, there were no significant differences at any time point for both AF ($F=0.20$; $p = 0.66$; $\eta_p^2 = 0.01$) and HF ($F=0.13$, $p = 0.72$; $\eta_p^2 = 0.01$), with the HT runners showing a greater angle at contact for both AF and HF, than the REC group. SC and SL both had no significant differences at any time point between groups however medium effect sizes were present for both variables (SC: $F = 0.94$; $p = 0.35$; $\eta_p^2 = 0.06$; SL: $F = 1.70$; $p = 0.21$; $\eta_p^2 = 0.11$). REC group had lower SC but a larger SL than the HT group throughout the test. KF and FTI showed no significant differences between groups at any time point, however there were large effect sizes present for both variables (KF: $F = 1.80$; $p = 0.20$; $\eta_p^2 = 0.12$; FTI: $F = 4.24$; $p = 0.06$; $\eta_p^2 = 0.24$). The REC group had a greater KF and FTI angle at contact than the HT group.

Figure 4.2. Estimated means of step cadence, stride length, ankle dorsiflexion, knee flexion, hip flexion and forward trunk inclination at contact, at the start (0%) (1), middle (50%) (2), and end (100%) (3) of an adapted trail test to exhaustion. Group 1 = recreational; Group 2 = highly trained.



DISCUSSION

The purpose of this study was to investigate if there are changes in running gait kinematics of highly trained and recreational trail runners during an adapted fatigue inducing trail running VO_2max test.

A key finding of the study is that significant differences were found for all variables for the whole group (n = 17) between the start and the end of the VO_2max test, indicating that there were kinematic changes that took place in response to fatigue. When speed and incline were not controlled for, there was no expectation to see large differences due to the speed and incline of the treadmill. However there were still meaningful differences observed as moderate to large effect sizes were found when controlling for speed and incline. Previous research [28; 29] indicates that not seeing large kinematic differences at the start of a test could be due to significant biomechanical changes only taking place in running gait just before exhaustion. According to a previous study, it is possible that the same differences are not present to a significant degree in a non-fatigued state [30]. The findings of the current study are in support of the results from previous research, with greater changes taking place between 50 – 100% of the test than from 0-50% of the test, for most of the kinematic variables (see Figure 4.2).

Without controlling for incline and speed, statistically significant differences were found for SL ($p < 0.01$) and KF ($p < 0.05$) at contact between the groups at the end of the VO_2max test. The recreational runners had a longer stride length and a greater KF angle at the end of the test, however, their cadence was lower than the highly trained group. The HT runners had a shorter stride length but a greater cadence and a smaller KF angle at contact. The HT runners maintained a similar stride length to what they had at the start of the test, and they increased their cadence as the test went on in order to accommodate the increasing speed and incline. These results could indicate that trail runners should try to maintain a higher SC and a shorter SL due to terrain variability, minimizing the kinematic alterations . Results from Padulo et al, (2013) showed that trained athletes change their step frequency and length in order to minimize the metabolic cost of running, with SF increasing by 2% at a gradient between 0-2% and as much as a 4.8% increase in SF when gradient increases up to 7%. These increases in SF were coupled with a proportional decrease in SL [31]. Similar findings were exhibited in the current study where the HT runners increased their SC and decreased their SL between the start and end of the test. The HT could be making use of a self-optimization strategy of adjustment, based on the elevation they're faced with. Dugan and Bhat, (2005) found that stride and step length fluctuate based on the runners ability to increase these lengths while velocity increases. This idea is supported by the findings of the current study, as HT runners could adjust their stride kinematics to accommodate the increasing speed, to a more efficient extent than the recreational runners, allowing the HT runners to run for longer until volitional exhaustion was reached.

When controlling for speed and incline, results from the repeated measures ANCOVA indicated no significant differences for any of the variables over time however medium to large effect sizes were observed (the partial eta squared values), indicating that greater differences might have been seen between conditions of fatigue if the sample size was bigger.

Although the group effect showed that there was no statistical significance difference between HT and REC the medium to large effect sizes that were seen for SC, SL, KF and FTI, between the two groups, indicate that there were differences in these variable between the two groups. These findings are similar to what other researchers have found. Preece et al, (2016) found that recreational runners had greater thoracic and pelvic inclination than elite runners as running speed increased, as the elite runners were able to maintain consistent FTI at all speeds observed. Koblbauer et al, (2014) saw changes in peak trunk flexion for novice runners with fatigue, the same was seen in the current study for both groups, where fatigue resulted in a large effect size for FTI between the two groups. The current study showed large effect sizes for changes in FTI over time and between the two groups, this could be due to the incline of the treadmill as well as the training status of the runners. HT runners maintained their FTI to a greater extent, even as the test went on. It is possible that trail runners should try to reduce large changes in their FTI, avoiding a hunched over running style despite feelings of fatigue, especially when runners are running at incline. Reducing large changes in FTI angle could be helpful for trail runner. Peak FTI angles cannot be commented on as they were not measured. The lack of significant results between the two groups from the current study could be due to a combination of factors, the main one being the training status of the runners. Despite being defined as 'recreational' runners, based on the inclusion criteria, the relative VO_2max results and the duration of their tests indicate that some of the recreational could have had the same physiological capacity at the time of testing as the highly trained group. If the recreational runners were better trained than recreational runners usually are, it would make detecting significant differences in running gait kinematics between the two groups difficult.

Both groups experienced changes in gait kinematics with time and as the speed and gradient increased throughout the VO_2max test. The rate of change between the two groups was the same with no significant time-group effect observed for any of the kinematic variables measured, illustrating that the runners responded in a similar way. No statistical significance was found to illustrate that recreational runners experienced less or more of a change in their running gait kinematics in comparison to the highly trained runners.

Dugan and Bhat, (2005) draw attention to the idea that training running gait kinematics and allowing the body to adapt over time will allow for a runner to achieve a running gait that requires a lesser amount of energy expenditure, allowing them to run for longer and at greater velocities, as the highly trained runners in this study managed to do. With time and specific training, it is possible that REC runners could undergo gait retraining that would enable them to run in a similar way to HT runners. The test in the current study however, did not take place at a constant speed, this could explain the changes in SC between the start and finish of the test. Runners would have had to increase their SC to accommodate the increasing speed of the treadmill, striding above their preferred rate due to the changing conditions (Dicharry et al, 2010).

CONCLUSION

The purpose of this study was to investigate if there are changes in running gait kinematics of highly trained and recreational trail runners after an adapted trail running VO_2max test. Data indicated that highly trained trail runners maintained their knee flexion angle and decreased their stride length to a greater extent than recreational trail runners despite the increased speed and gradient of treadmill, with recreational runners showing a larger angle for knee flexion at contact and a longer stride length.

When controlling for speed and incline of the treadmill, there were no statistically significant differences in gait kinematics over time, however medium to large effect sizes for SC, SL, ADF, KF and FTI were reported. With a larger group of participants or perhaps a longer test to exhaustion, significant changes over time would most likely have been observed for running gait kinematics.

ACKNOWLEDGEMENTS

The author would like to thank the participants for their time and willingness to participate in the research project as well as the Neuromechanics Unit of the Central Analytical Facilities at Stellenbosch University for the use of their facilities and their analytical support. A further thanks is extended to the Division of Epidemiology and Biostatistics, Faculty of Medicine and Health Sciences for their support and guidance in statistical analyses.

CONFLICTS OF INTEREST

The authors declare that there are no known conflicts of interest.

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CHAPTER FIVE - CONCLUSION

5.1 INTRODUCTION

Despite the fact that trail running has become a popular sport, consistently growing in the number of participants both internationally and locally, limited research is available on running gait kinematics of trail runners. This study aimed to answer two questions relating to trail running: firstly, if highly trained trail runners have different running gait kinematics during submaximal level treadmill running compared to recreational trail runners, and secondly, if a treadmill run to exhaustion will affect the running gait kinematics of highly trained and recreational trail runners.

Because of the article format thesis, this chapter will not be presented in the usual format of a generic thesis. The discussion in Chapter Four replaces some of the content that would typically feature in a Discussion chapter. It should be noted that limited published research on trail running-specific kinematics makes it difficult to compare findings from the current study to previous research.

A conclusion based on the stated questions, aims and hypotheses will be presented in this chapter. A summary of the study results will be presented in Table 5.1. Mention will be given to the practical applications of the study findings, study limitations, and potential opportunities for future research will be noted.

5.2 COMPARISON OF SELECTED RUNNING GAIT KINEMATICS BETWEEN HIGHLY TRAINED AND RECREATIONAL TRAIL RUNNERS DURING SUBMAXIMAL LEVEL TREADMILL RUNNING

Through the current study, the researcher firstly, wanted to determine if highly trained trail runners have different running gait kinematics, during submaximal level treadmill running (0° incline and 10km/h), compared to recreational trail runners. It was hypothesized that there would be significant differences between the highly trained and recreational trail runners for the mentioned kinematic variables during submaximal treadmill running. The null hypothesis (H_0) stated that there would be no significant differences between the highly trained and recreational trail runners for the selected kinematic variables during submaximal level treadmill running ($H0: \mu1= \mu2$). The null hypothesis is accepted.

Results indicated that during submaximal running there was a significant difference for KF ($p < 0.05$) and were no significant differences in SC, SL, AF, KF, HF and FTI between HT and REC trail runners during submaximal level treadmill running. In the context of this study, this finding could be due to the training status of the two groups, where the REC group is better trained than recreational runners usually are, resulting in non-significant differences during submaximal running. The speed at which participants were required to run also could have influenced the outcome. Previous research indicates that large kinematic adjustments only take place at speeds greater than submaximal running (Derrick and Mclean, 2002; Gazeau et al, 1997). Results from the current study support the idea that large kinematic adjustments may not be seen at submaximal running. If this is the case, then it could mean that gait technique and training should take place under varying conditions of fatigue. In a non-fatigued state the REC runners managed to maintain reasonable kinematics. A nuanced finding may also be that REC runners should work on KF at submaximal pace, which could translate to less change in KF angle in a fatigued condition or at least a delay in fatigue/improved performance for longer.

5.2.1 COMPARISON OF SELECTED RUNNING GAIT KINEMATICS BETWEEN HIGHLY TRAINED AND RECREATIONAL TRAIL RUNNERS DURING AN ADAPTED TRAIL RUNNING VO_2MAX TEST

It was hypothesized that highly trained runners will maintain their gait kinematics during an adapted trail running VO_2max test to a greater extent than the recreational runners, under fatigue.

The null hypothesis (H_0) stated that there would be no significant differences between the highly trained and recreational trail runners for the mentioned kinematics over the duration of the adapted trail running VO_2max test (H_0: $\mu 1= \mu 2$). The null hypothesis (H_0) is rejected. Statistically significant differences were found between the groups at the end of the adapted VO_2max test for SL ($p < 0.01$) and KF ($p < 0.02$). Despite a lack of statistical significance for the other kinematic variables, medium to large effect sizes were observed between the groups for SC, SL, ADF, KF and TI at contact.

Between groups, medium to large effect sizes were also seen for SC, SL, KF and TI. This lack of significance in the results could be due to multiple reasons. The most notable reason being that the recreational group may have been better trained than most recreational runners are. Previous research, on 97 recreational endurance runners, indicates VO_2max values that range between 55.7 - 63.3 for recreational runners whereas this study reported a mean value of 66.20 ±5.12 (Gordan et al , 2017).

While there was a notable difference in VO_2max performance between the HT and REC groups, the fact that the REC group was fitter than originally hypothesized might mean that their running gait kinematics were also better than originally hypothesized, making the observation of kinematic differences between these two groups difficult. Previous research compared kinematics between distinctly different groups, such as between novice and competitive runners (Maas et al, 2017). Although this study compared REC to HT runners, the REC group had high VO_2max values that were closer to the values of the HT group than they typically should be, indicating that the difference in training status may not have been clear enough. As well as this, the adapted trail VO_2max test was a relatively short protocol. There may not have been enough time for kinematic adjustments to take place before the test was over. Scheer et al, (2018) used this protocol to successfully show that trail runners performed better in an uphill VO_2max test in comparison to a standard horizontal protocol, most likely due to the test being sport-specific for the participants. The sport-specific element was positive for the current study as the participants were also trail runners, however the VO_2max for the current study was used for descriptive purposes whereas the kinematics were the main focus of the current study. The short test could elicit valuable information in terms of VO_2max values for the participants but it may not have been the best choice when taking kinematic change into account.

5.2 SUMMARY OF THE OUTCOME OF THE STUDY

Table 5.1: A summary of the hypothesis and outcomes based on the variables assessed.

Hypotheses	Variables			
	Rejected	**Outcomes**	**Accepted**	**Outcomes**
1. The null hypothesis (H_0) stated that there would be no significant differences between the highly trained and recreational trail runners for the mentioned kinematic variables during submaximal level treadmill running. Accepted.	KF	Statistically significant difference (*p* < 0.05)	SL, SC, ADF, HF and FTI.	No statistically significant difference between recreational and highly trained.
2. The null hypothesis (H_0) stated that there would be no significant differences between highly trained an recreational trail runners for the mentioned kinematic variables during the adapted trail running VO_2max test. Rejected.	SL and KF	Statistically significant difference (*p* <0.05)	SC, SL, ADF, KF and FTI	No statistically significant difference between groups was found but a medium to large effect size was observed.

5.3 PRACTICAL APPLICATIONS

In conclusion, this study had shown that there are some kinematics differences present between highly trained and recreational trail runners after a fatigue protocol. The effect sizes also demonstrate that with a greater sample size, significant differences may be observed for the previously mentioned kinematics during an adapted trail VO_2max test.

Understanding running gait kinematics and that there are differences between these two groups can assist runners in improving their performance and improve understanding in how the body's kinematics respond to fatigue. Based on statistically significant differences and the medium to large effects sizes in the current study, some coaching guidelines could be suggested for trail runners (Table 5.2). These coaching guidelines are based on the results from the current that was supported by previous research.

Table 5.2: Suggested coaching guidelines based on the specific results from the current study and supported by previous research

Variable	**Outcome**	**Coaching guidelines**
Step cadence	HT participants had a greater SC.	A SC of ±180 steps per minute is seen as an economical cadence for road runners. For trail runners is could be slightly more. Maintaining that high cadence on incline even when fatigued might also improve performance.
Stride length	HT participants had a shorter SL.	A short SL in combination with an greater SC could help runners navigate terrain variability.
Ankle angle at contact	HT participants had greater AF at contact.	Greater AF at contact combined with a smaller KF angle at contact could aid with increase leg stiffness and weight acceptance.
Knee angle at contact	HT participants had a smaller KF angle at contact.	A smaller KF angle plays a role in greater leg stiffness which

		contributes to a more economic running technique.
Hip angle at contact	HT participants had a smaller HF angle at contact.	A smaller HF angle could help the runner not to overstride and to maintain better leg stiffness.
Trunk forward inclination	FTI was greater for REC participants, meaning they were more upright during the run.	Runners should try to maintain their FTI, especially when faced with increasing gradient and avoid hunching over as this restricts lung capacity and shuttling of O_2 to working muscles.

Recommending one economical running technique for all runners should, however, be approached with caution. There is variability in gait kinematics between and within groups that indicates there is not necessarily one running technique that will work for all runners.

5.4 STUDY LIMITATIONS

Limitations to the current study are acknowledged and should be mentioned. The first limitation of this study is a reduced ecological validity due to indoor testing. This study did manage to take place on incline, which is in favour of the uphill running adaptations that trail runners tend to have. However, the test did not take place on a trail surface which is a limiting factor. The second is the adapted trail fatigue protocol. The test could have been too short to elicit the biomechanical responses to fatigue and instead acute muscular fatigue takes place, causing some kinematic changes but not to the same extent a longer test would have had.

Runners were instructed to run to volitional exhaustion for the VO_2max test. RPE and HR monitoring was done as well as looking at RER values to get the best idea if the results were indicative of a maximal effort or not, however the researcher cannot be completely certain that runners did so and ran to the best of their ability to the duration of the test. As well as this, trail running is a sport that takes place on undulating terrain with successive bouts of ascent and descent. This type of terrain could not be replicated in the lab and all the testing took place on the smooth surface of the treadmill, although the treadmill did incline, it was not an accurate representation of the type of terrain the runners are used to. This could have influenced the type of kinematic changes that was seen throughout the test. Another limitation for this study could have been the grouping of the athletes. The REC runners seemed to have sound kinematics at the beginning of the test, perhaps because they're used to shorter distance running and were adapted for short bout efforts whereas the HT runners were ultra-runners, who were used to performing over prolonged distances and time.

5.5 RESEARCH RECOMMENDATIONS

A future recommendation would be to have a field-based study, assessing trail runners on the terrain that they’re accustomed to using portable testing equipment and specific study design. Future research should focus on a combination of RE, kinematics, kinetics, neuromuscular and physiological aspects and apply an inclusive approach to better understanding running gait kinematics and kinetics.

A future study could also group the participants differently, perhaps by using participants from a pre-existing race and grouping them based on performance in said race. Future studies could investigate these effects over a longer period of time (with a real-word time trail or repeated trials) to see if there is in fact a significant trend in the differences over time between the two groups. However, trail runners can benefit from a better understanding of running gait kinematics and the changes that take place when exposed to various conditions, allowing them to make adjustments to their training.

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APPENDIX A

AUTHOR GUIDELINES FOR GAIT & POSTURE

JOURNAL DESCRIPTION

Gait and Posture publishes new and innovative basic and clinical research on all aspects of human movement, locomotion and balance.

The topics covered include: Techniques for the measurement of **gait** and **posture,** and the standardization of results presentation; Studies of normal and **pathological gait**; Treatment of gait and **postural abnormalities**; Biomechanical and theoretical approaches to gait and posture; Mathematical models of **joint** and **muscle mechanics**; **Neurological** and **musculoskeletal** function in gait and posture; The evolution of **upright posture** and **bipedal locomotion**; Adaptations of carrying loads, walking on uneven surfaces, climbing stairs, running and performing other movements. Spinal biomechanics only if they are directly related to gait and/or posture and are of general interest to our readers; The effect of aging and development on gait and posture; Psychological and cultural aspects of gait; Patient education.

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Immediately after the abstract, provide a maximum of 6 keywords, using American spelling and avoiding general and plural terms and multiple concepts (avoid, for example, 'and', 'of').

Be sparing with abbreviations: only abbreviations firmly established in the field may be eligible. These keywords will be used for indexing purposes.

Formatting of funding sources

List funding sources in this standard way to facilitate compliance to funder's requirements:

Funding: This work was supported by the National Institutes of Health [grant numbers xxxx, yyyy]; the Bill & Melinda Gates Foundation, Seattle, WA [grant number zzzz]; and the United States Institutes of Peace [grant number aaaa].

It is not necessary to include detailed descriptions on the program or type of grants and awards. When funding is from a block grant or other resources available to a university, college, or other research institution, submit the name of the institute or organization that provided the funding.

If no funding has been provided for the research, please include the following sentence:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Artwork

Electronic artwork

General points

1. Make sure you use uniform lettering and sizing of your original artwork.
2. Embed the used fonts if the application provides that option.
3. Aim to use the following fonts in your illustrations: Arial, Courier, Times New Roman, Symbol, or use fonts that look similar.
4. Number the illustrations according to their sequence in the text.
5. Use a logical naming convention for your artwork files.
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EPS (or PDF): Vector drawings, embed all used fonts.
TIFF (or JPEG): Color or grayscale photographs (halftones), keep to a minimum of 300 dpi.
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2. Supply files that are too low in resolution;

3. Submit graphics that are disproportionately large for the content;
4. Supply more than 6 figures per manuscript.

References

All author names should be listed unless there are more than 6 authors, in which case the first 6 names should be listed followed by “et al.”

Data references
This journal encourages you to cite underlying or relevant datasets in your manuscript by citing them in your text and including a data reference in your Reference List. Data references should include the following elements: author name(s), dataset title, data repository, version (where available), year, and global persistent identifier. Add [dataset] immediately before the reference so we can properly identify it as a data reference. The [dataset] identifier will not appear in your published article.
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Most Elsevier journals have their reference template available in many of the most popular reference management software products. These include all products that support Citation Style Language styles, such as Mendeley. Using citation plug-ins from these products, authors only need to select the appropriate journal template when preparing their article, after which citations and bibliographies will be automatically formatted in the journal's style. If no template is yet available for this journal, please follow the format of the sample references and citations as shown in this Guide. If you use reference management software, please ensure that you remove all field codes before submitting the electronic manuscript. More information on how to remove field codes from different reference management software.
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Text: Indicate references by number(s) in square brackets in line with the text. The actual authors can be referred to, but the reference number(s) must always be given.
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List: Number the references (numbers in square brackets) in the list in the order in which they appear in the text.
Examples:
Reference to a journal publication:
[1] J. van der Geer, J.A.J. Hanraads, R.A. Lupton, The art of writing a scientific article, J. Sci. Commun. 163 (2010) 51–59. https://doi.org/10.1016/j.Sc.2010.00372.
Reference to a journal publication with an article number:
[2] J. van der Geer, J.A.J. Hanraads, R.A. Lupton, 2018. The art of writing a scientific article. Heliyon. 19, e00205. https://doi.org/10.1016/j.heliyon.2018.e00205.
Reference to a book:
[3] W. Strunk Jr., E.B. White, The Elements of Style, fourth ed., Longman, New York, 2000.
Reference to a chapter in an edited book:
[4] G.R. Mettam, L.B. Adams, How to prepare an electronic version of your article, in: B.S. Jones, R.Z. Smith (Eds.), Introduction to the Electronic Age, E-Publishing Inc., New York, 2009, pp. 281–304.
Reference to a website:
[5] Cancer Research UK, Cancer statistics reports for the UK. http://www.cancerresearchuk.org/aboutcancer/statistics/cancerstatsreport/, 2003 (accessed 13 March 2003).
Reference to a dataset:
[dataset] [6] M. Oguro, S. Imahiro, S. Saito, T. Nakashizuka, Mortality data for Japanese

oak wilt disease and surrounding forest compositions, Mendeley Data, v1, 2015. https://doi.org/10.17632/xwj98nb39r.1.

Data visualization

Include interactive data visualizations in your publication and let your readers interact and engage more closely with your research. Follow the instructions here to find out about available data visualization options and how to include them with your article.

Supplementary material

Supplementary material such as applications, images and sound clips, can be published with your article to enhance it. Submitted supplementary items are published exactly as they are received (Excel or PowerPoint files will appear as such online). Please submit your material together with the article and supply a concise, descriptive caption for each supplementary file. If you wish to make changes to supplementary material during any stage of the process, please make sure to provide an updated file. Do not annotate any corrections on a previous version. Please switch off the 'Track Changes' option in Microsoft Office files as these will appear in the published version.

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This journal encourages and enables you to share data that supports your research publication where appropriate, and enables you to interlink the data with your published articles. Research data refers to the results of observations or experimentation that validate research findings. To facilitate reproducibility and data reuse, this journal also encourages you to share your software, code, models, algorithms, protocols, methods and other useful materials related to the project.

Below are a number of ways in which you can associate data with your article or make a statement about the availability of your data when submitting your manuscript. If you are sharing data in one of these ways, you are encouraged to cite the data in your manuscript and reference list. Please refer to the "References" section for more information about data citation. For more information on depositing, sharing and using research data and other relevant research materials, visit the research data page.

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If you have made your research data available in a data repository, you can link your article directly to the dataset. Elsevier collaborates with a number of repositories to link articles on ScienceDirect with relevant repositories, giving readers access to underlying data that gives them a better understanding of the research described.

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If preferred, you can still choose to annotate and upload your edits on the PDF version. All instructions for proofing will be given in the e-mail we send to authors, including alternative methods to the online version and PDF.
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APPENDIX B

RECRUITMENT FLYER

APPENDIX C

PARTICIPANT INFORMATION LEAFLET AND INFORMED CONSENT FORM (ENGLISH)

TITLE OF RESEARCH PROJECT(S):	
Stellenbosch Trail and Road Running Research (STARRR) **The acute kinetic and kinematic differences between shod, barefoot and minimalist sandal running in habitually shod male recreational trail runners. – Matthew Swart** **The difference in running gait kinematics between highly trained and recreational trail runners before and after a fatigue stimulus – Emily Robertson** **The differences in lower-body muscle force production and gait variables during treadmill and trail running in recreational trail runners – Oloff Bergh**	
DETAILS OF PRINCIPAL INVESTIGATORS (PIs):	
Title, first name, surname: **Mr Matthew Swart,** **Ms Emily Robertson** **Mr Oloff Bergh** **Prof. Ranel Venter (Supervisor)** **Mr. Simon De Waal (Co-supervisor)**	**Ethics reference number:** **N19/07/077 – M. Swart** **N19/07/078- E. Robertson** **N19/07/076 – O. Bergh** **N19**
Full postal address: **10 Alphen Glade, 23 Upper Mountain Road, Somerset West, 7130** **Unit 6, Tassenywk, Marais Street Stellenbosch, 7600** **13 Goederust Street, Heldervue, Somerset West 7130**	**PIs' Contact numbers:** **079 346 8688 – M. Swart** **072 261 5045 – E. Robertson** **079 299 4974 – O. Bergh**

We would like to invite you to take part in a collaborative STARRR project at the Department of Sport Science, Stellenbosch University. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study PIs or supervisor/ co-supervisor any questions about any part of this project that you do not fully understand. It is very important that you are completely satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. In other words, you may choose to take part, or you may choose not to take part. Nothing bad will come of it if you say no: it will not affect you negatively in any way whatsoever. Refusal to participate will involve no penalty or loss of benefits or reduction in the level of care to which you are otherwise entitled to. You are also free to withdraw from the study at any point, even if you do agree to take part initially.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University.** The study will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, the South African Guidelines for Good Clinical Practice (2006), the Medical Research Council (MRC) Ethical Guidelines for Research (2002), and the Department of Health Ethics in Health Research: Principles, Processes and Studies (2015).

What is the STARRR group?

The STARRR group is a research team of three masters students (Matthew Swart, Emily Robertson and Oloff Bergh) from the Department of Sport Science, Stellenbosch University, led by two academic staff and supervisors (Professor Ranel Venter and Mr Simon De Waal). The group was formed due to a common interest in running research. Due to this common interest we will be sharing resources for the testing process. The result of this being that you have the opportunity to participate in all three masters research projects over a two day testing period. Your participation in this research will thus form part of all three projects however you may opt out of any of the projects before, during or after testing without having to state a reason. Please indicate in the boxes below which specific masters research project(s) you would be willing to take part in.

What are the research studies about?

1. **The acute kinetic and kinematic differences between shod, barefoot and minimalist sandal running in habitually shod male recreational trail runners – Matthew Swart**

The purpose of this study is to determine the acute kinematic and kinetic differences between running in shoes, running barefoot and running in minimalist sandals. Kinematics refers to the movement or motion of body parts without taking into account the forces that produce these movements (i.e. stride length and stride frequency). Kinetics refers to the forces and time that act on the body during these movements (i.e. ground reaction forces). This study aims to compare certain variables whilst running in three different footwear conditions, namely in your conventional trail running shoes, in Xero (Xero Shoes, Colorado, U.S.A) minimalist sandals and barefoot in order to compare the differences.

2. **The difference in running gait kinematics between highly trained and recreational trail runners before and after a fatigue stimulus – Emily Robertson**

The purpose of the study is to learn more about what the effect of fatigue is on running kinematics (the motion of running) for highly trained and recreational runners and if the margin of difference is large between these two groups. In this study kinematics variables such as forward trunk lean, cadence, knee angles etc. will be compared between the two samples of runners.

3. **The differences in lower-body muscle force production and gait variables during treadmill and trail running in recreational trail runners – Oloff Bergh**

During this study we would like to further explore the intricacies of human running, and the effect of changing surfaces on muscle activities. More specifically, looking at muscle force production changes when individuals go from a treadmill run to a more real-world setting, such as trail running. We are very lucky to have an abundance of natural environments to run in as well as perfect weather conditions for most of the year, however not all have these privileges and run on treadmills or road surfaces regularly.

Due to the growing popularity of weekly off-road running events such as the Parkrun™ and Myrun™, the greater community of recreational runners (both road and trail) will benefit from knowing the changes that occur in the lower body kinetics when changing running surface and terrain. We must identify the changes that occur in the lower-body muscles when we traverse these complex trail terrains.

All the testing will be hosted by the Department of Sport Science, Stellenbosch University, and will take place at the Neuromechanics unit within the Central Analytical facilities (CAF) laboratory which is situated at Coetzenburg behind Maties Gymnasium. The total amount of participants needed for this study is 30 (15 recreational and 15 elite trail runners) with all participants required to complete the testing at the Neuromechanics unit.

Why do we invite you to participate?

In order to participate in any of the three masters' research projects within the STARRR group, you need to be familiar with the sport of trail running. Additionally, you need to have had no previous experience with minimalist running (i.e. have run barefoot or in sandals during training and racing). We have invited two levels of training status / runner to participate in the STARRR projects – recreational and highly trained. If you regularly run on trail between 20 – 30km per week, you qualify as a recreational trail runner. If you regularly run on trail between 60 – 90km per week, you qualify as a highly trained trail runner. Your participation will help make a significant contribution to the body of literature surrounding trail running.

What will your responsibilities be?

Day 1

1. You will be briefed on the testing proceedings of the day and subsequently in order to participate, you will have to sign this form.
2. Anthropometric data (weight, height, limb length, etc.) will be measured.
3. VO2max test (high intensity running effort on a treadmill)
4. Time to Exhaustion Test at 90% of VO2max at a 7degree incline. (Runners will run until volitional exhaustion is reached)

Day 2

1. Vertical jump testing (3x3 Jumps in normal shoes) - Submaximal running while wearing your running shoes.
2. Submaximal running in a barefoot condition.
3. The participants will run for one minute at three different speeds (8, 10 and 13km/h) on the treadmill in a shod and unshod condition. This will be done first at incline (8 degrees), then level running (0 degrees) then at decline (-8 degrees).

Will you benefit from taking part in this research?

You will not benefit directly from participating in this study. This study will however benefit the greater community of trail and recreational runners. In addition, you will acquire in depth knowledge of your own running mechanics and exposure to the research process.

Are there any risks involved in your taking part in this research?

The study will be conducted in a safe environment which will be regulated by the researchers to ensure the safety of the participant. The anthropometric tests will be conducted in a laboratory with all risks being taken into consideration, including a thorough cleaning of the laboratory prior to the commencement of testing, a none slip mat used whilst attaching equipment and safety harness for the treadmill running. You will also be required to run a short pre-selected outdoor trail adjacent to the laboratory. It is a nontechnical single-track that should pose little to no risk for recreational trail runners. You will be required to use your own trail running shoe to ensure maximum comfort and less injury risk during the shod trial. For the barefoot trial, the treadmill as well as the CAF lab will be swept and cleaned prior to the commencement of the study in order to ensure safe and clean running conditions for the exposed foot. You are also allowed a familiarization with the minimalist sandal in order to determine a comfortable lacing pattern. All equipment used will be non-invasive and will be strapped on the specific bony landmark locations (ankles, knees, hips, lumbar spine and thoracic spine) using soft foam straps.

If you do not agree to take part, what alternatives do you have?

If participants do not agree to take part, they may drop out of the study or opt to participate in select studies or an alternative research project where they agree to the terms.

Even though it is unlikely, what will happen if you get injured somehow because you took part in this research study?

Stellenbosch University will provide comprehensive no-fault insurance and will pay for any medical costs that came about because participants took part in the research. The participant will not need to prove that the researcher was at fault.

Will you be paid to take part in this study and are there any costs involved?

There will be no payment for participation. However participants will receive a full report with the results of their testing and a practical explanation of what these results mean. After testing is completed, participants will have the option to book an appointment of 1 hour with one of the researchers. In this hour we will answer any questions that participants have about their running gait kinematics and offer advice to them in a sports science capacity.

Is there anything else that you should know or do?

1. You should tell your family practitioner or usual doctor that you are taking part in a research study. If you have been warned against participating in **maximal exercise** by a doctor, then please opt not to participate in Emily's study.
2. You should also tell your medical insurance company that you are participating in a research study.
3. You can phone the Health Research Ethics Committee at 021 938 9677/9819 if there still is something that your study doctor has not explained to you, or if you have a complaint.
4. You will receive a copy of this information and consent form for you to keep safe.

Decision to participate:
(Please indicate with a tick which research projects you are willing to participate)

☐ **The acute kinetic and kinematic differences between shod, barefoot and minimalist sandal running in habitually shod male recreational trail runners – <u>Matthew Swart</u>**

☐ **The difference in running gait kinematics between highly trained and recreational trail runners before and after a fatigue stimulus – <u>Emily Robertson</u>**

Highly trained runners may only participate in this study

☐ **The differences in lower-body muscle force production and gait variables during treadmill and trail running in recreational trail runners – <u>Oloff Bergh</u>**

Declaration by participant:

By signing below, I ……………………………….………… agree to take part in a/these research study entitled:

☐ **The acute kinetic and kinematic differences between shod, barefoot and minimalist sandal running in habitually shod male recreational trail runners – <u>Matthew Swart</u>**

☐ **The difference in running gait kinematics between highly trained and recreational trail runners before and after a fatigue stimulus – <u>Emily Robertson</u>**

Highly trained runners may only participate in this study

☐ **The differences in lower-body muscle force production and gait variables during treadmill and trail running in recreational trail runners – <u>Oloff Bergh</u>**

I declare that:

1. I have read this information and consent form, or it was read to me, and it is written in a language in which I am fluent and with which I am comfortable.
2. I have had a chance to ask questions and I am satisfied that all my questions have been answered.
3. I understand that taking part in this study is **voluntary,** and I have not been pressurised to take part.
4. I may choose to leave the study at any time and nothing bad will come of it – I will not be penalised or prejudiced in any way.
5. I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan that we have agreed on.

Signed at (*place*) ....…........……………. on (*date*) …………....…… 2019.

....	....
Signature of participant	**Signature of witness**

Declaration by investigator:

I *(name)* ……………………………………………… declare that:

1. I explained the information in this document in a simple and clear manner to ○ ………………………………

2. I encouraged him/her to ask questions and took enough time to answer them.

3. I am satisfied that he/she completely understands all aspects of the research, as discussed above.

4. I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.)*

Signed at (*place*) ....….......…………….. on (*date*) …………....…… 2019.

....

Signature of investigator

....

Signature of witness

APPENDIX D

PARTICIPANT INFORMATION LEAFLET AND INFORMED CONSENT FORM (AFRIKAANS)

TITEL VAN DIE PROJEK(TE):	
<u>**Stellenbosch Trail and Road Running Research (STARRR)**</u> **Die akute kinetiese en kinematiese verskille tussen normale skoene, kaalvoet- en minimalistiese sandale wat gewoonlik in manlike ontspanningsroetes aangebied word – Matthew Swart** **Die verskil in hardloopgang kinematika tussen hoogs opgeleide en ontspanningsroetes hardlopers voor en na 'n moegheidstimulus – Emily Robertson** **Die verskille in die produksie van laer liggaamsspierkrag en gangveranderlikes tydens loopband en roete by ontspanningsroete hardlopers– Oloff Bergh**	
BESONDERHEDE VAN DIE PRIMERE ONDERSOEKER(S):	
Titel, eerste naam, van: **Mr Matthew Swart,** **Ms Emily Robertson** **Mr Oloff Bergh** **Prof. Ranel Venter (Supervisor)** **Mr. Simon De Waal (Co-supervisor)**	**Etiek verwysings normmers:** **N19/07/077 – M. Swart** **N19/07/078- E. Robertson** **N19/07/076 – O. Bergh** **N19**
Volledige posadres: **10 Alphen Glade, 23 Upper Mountain Straat, Somerset West, 7130** **Unit 6, Tassenywk, Marais Straat Stellenbosch, 7600** **13 Goederust Straat, Heldervue, Somerset West 7130**	**Kontak Nommers:** **079 346 8688 – M. Swart** **072 261 5045 – E. Robertson** **079 299 4974 – O. Bergh**

Ons wil jou nooi om deel te neem aan 'n samewerkende STARRR-projek aan die Departement Sportwetenskap, Universiteit Stellenbosch. Neem die tyd om die inligting wat hier aangebied word, te lees, wat die besonderhede van hierdie projek uiteensit. Vra die studie-PI's of studieleier / medestudieleier enige vrae rakende enige deel van hierdie projek wat jy nie ten volle verstaan nie. Dit is baie belangrik dat jy heeltemal tevrede is dat jy duidelik verstaan wat hierdie navorsing behels en hoe jy betrokke gaan wees. Jou deelname is ook heeltemal vrywillig en jy is vry om te weier om deel te neem. Met ander woorde, jy kan kies om deel te neem, of kies om nie deel te neem nie. Niks slegs sal daaruit kom as jy nee sê nie: dit sal jou nie negatief be ïnvloed nie. Weiering om deel te neem behels geen boete of verlies aan voordele of verlaging in die versorgingsvlak waarop u andersins geregtig is nie. Jy kan ook op enige stadium uittree uit die st udie, selfs al stem jy in om aanvanklik deel te neem.

*This study has been approved by the Health Research Ethics Committee at Stellenbosch University. The study will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, the South African Guidelines for Good Clinical Practice (2006), the Medical Research Council (MRC) Ethical Guidelines for Research (2002), and the Department of Health Ethics in Health Research: Principles, Processes and Studies (2015).

Wat is die STARRR-groep?
Die STARRR-groep is 'n navorsingspan van drie meestersstudente (Matthew Swart, Emily Robertson en Oloff Bergh) van die Departement Sportwetenskap, Universiteit Stellenbosch, onder leiding van twee akademiese personeel en studieleiers (professor Ranel Venter en mnr Simon De Waal). Die groep is gestig as gevolg van 'n gemeenskaplike belangstelling in navorsing. Weens hierdie gemeenskaplike belangstelling deel ons bronne vir die toetsproses. Die resultaat hiervan is dat jy die geleentheid het om oor 'n twee dae toetsperiode aan al drie meestersnavorsingsprojekte deel te neem. Jou deelname aan hierdie navorsing sal dus deel vorm van al drie die projekte, maar jy kan van die projekte voor, tydens of na toetsing intree sonder om 'n rede daarvoor te gee. Dui in die blokkies onder aan watter spesifieke meestersnavorsingsprojek (te) jy bereid sou wees om aan deel te neem.

Waaroor gaan elke studie?
1) Die akute kinetiese en kinematiese verskille tussen normale skoene, kaalvoet- en minimalisti ese sandale wat gewoonlik in manlike ontspanningsroetes aangebied word – Matthew Swart
Die doel van hierdie studie is om die akute kinematiese en kinetiese verskille tussen hardloop in skoene, kaalvoet en hardloop in mini malistiese sandale te bepaal. Kinematika verwys na die beweging of beweging van liggaamsdele son der om rekening te hou met die kragte wat hierdie bewegings voortbring (d.w.s. skyflengte en skyffrekwensie). Kinetika verwys na die kragte en tyd wat tydens hierdie bewegings op die liggaam inwerk (d.w.s. grondreaksiekragte). Hierdie studie het die doel om sekere veranderlikes te vergelyk tydens hardloop in drie verskillende skoene, naamlik in jou gewone skoene, in Xero (Xero Shoes, Colorado, U.S.A) minimalistiese sandale en kaalvoet om die verskille te vergelyk.

2) Die verskil in hardloopgang kinematika tussen hoogs opgeleide en ontspanningsroetes hardl opers voor en na 'n moegheidstimulus – Emily Robertson
Die doel van die studie is om meer te weet oor die effek van uitputting op hardloopkinematika (hardloopbeweging) vir hardlop ers en ontspanningslopers, en of die verskil tussen hierdie twee groepe groot is. In hierdie studie word kinematiese veranderlikes soos voorwaartse romp, kadens, kniehoeke, ens. Vergelyk tussen die twee groepe van hardlopers.

3) Die verskille in die produksie van laer liggaamsspierkrag en gangveranderlikes tydens loopband en roete by ontspanningsroete hardlopers– Oloff Bergh

Tydens hierdie studie wil ons die ingewikkeldhede van menslike hardloop en die effek van veranderende oppervlaktes op spieraktiwiteite verder ondersoek. Meer spesifiek, word gekyk na die produksie van spierkrag wanneer individue van 'n trapmeulbaan na 'n meer regte wêreld gaan, soos spoorloop. Ons is baie gelukkig om 'n oorvloed van natuurlike omgewings te hê, sowel as perfekte weersomstandighede vir die grootste deel van die jaar, maar nie almal het hierdie voorregte nie en loop dus meer gereeld op loopbane of padoppervlakke. Vanweë die toenemende gewildheid van weeklikse veldrenne soos Parkrun ™ en Myrun ™, sal die groter gemeenskap van ontspanningslopers (beide pad en roete) baat vind by die kennis van die veranderinge wat plaasvind in die kinetika van die onderlyf wanneer die loopoppervlak verander word en terrein. Ons moet die veranderinge wat plaasvind in die onderlyfspiere identifiseer wanneer ons hierdie komplekse roeteterreine deurkruis.

Al die toetse word aangebied deur die Departement Sportwetenskap, die Universiteit Stellenbosch, en sal plaasvind by die Neuromechanics-eenheid in die Central Analitiese Fasiliteite (CAF) laboratorium wat op Coetzenberg agter Maties Gimnasium geleë is. Die totale hoeveelheid deelnemers wat benodig word vir hierdie studie is 30 (15 ontspannings- en 15 opgeleide-spoorlopers), met alle deelnemers wat nodig is om die toetsing by die Neuromechanics-eenheid te voltooi.

Hoekom nooi ons jou om deel te neem?
Om aan een van die drie meestersnavorsingsprojekte in die STARRR-groep deel te neem, moet jy vertroud wees met die sportsoort. Daarbenewens hoef jy geen vorige ervaring met minimalistiese hardloop te hê nie (dit wil sê kaalvoet of in sandale tydens hardloop en wedrenne). Ons het twee vlakke van opleidingstatus / naaswenner uitgenooi om aan die STARRR-projekte deel te neem - ontspannend en hoogs opgelei. As jy gereeld tussen 20 - 30 km per week op die roete hardloop, kwalifiseer jy as 'n ontspanningsroete. As jy gereeld tussen 60 - 90km per week op die baan hardloop, kwalifiseer jy as 'n hoogs opgeleide baanloper. Jou deelname sal help om 'n belangrike bydrae te lewer tot die literatuur rondom spoorhardloop.

Wat sal jou verantwoordelikhede wees?
<u>Dag 1</u>

- Jy word ingelig oor die dag se toetsverrigtinge en jy moet dan hierdie vorm onderteken om deel te neem.
- Antropometriese data (gewig, lengte, lengte van die ledemaat, ens.) word gemeet.
- VO2max-toets (harde inspanning op 'n trapmeul)
- Tyd vir uitputtingstoets teen 90% van VO2max teen 'n helling van 7 grade. (Hardlopers hardloop totdat die uitputting bereik is)

<u>Dag 2</u>

- Vertikale springtoets (3x3 spring in normale skoene)
- Submaksimale hardloop terwyl u drafskoene dra.
- Gerandomiseer tot submaximale hardloop in 'n kaalvoet of minimalistiese sandale toestand.

- Die deelnemers hardloop vir een minuut met drie verskillende snelhede (8, 10 en 13 km / u) op die loopband in 'n onbehandelde toestand. Dit word eers gedoen met 'n helling (8 grade), dan vlak hardloop (0 grade) en dan met afname (-8 grade).

Sal u voordeel trek uit hierdie navorsing?
Jy sal nie direk baat vind by
die deelname aan hierdie studie nie. Hierdie studie sal egter die groter gemeenskap van pad- en ontspanningslopers bevoordeel. Daarbenewens verwerf jy 'n diepgaande kennis van jou eie h ardloopmeganika en blootstelling aan die navorsingsproses. Ons sal ook ‘n gelukkige trekking waar vier deelnemers 'n gratis Xero-skoen (Xero Shoes, Colorado, U.S.A) in sandale kan wen.

Is daar enige risiko verwant aan die deelname aan hierdie studie?
Die studie sal uitgevoer word in 'n veilige omgewing wat deur die navorsers gereguleer sal word om die deelnemer se veiligheid te verseker. Die antropometriese toetse sal in 'n laboratorium uitgevoer word, met alle risiko's wat in aanmerking geneem word, insluitend 'n deeglike skoonmaak van die laboratorium voor die aanvang van die toets, 'n matglipmat wat gebruik word terwyl toerusting en veiligheidsnoer aangebring word vir die loopba nd. Daar sal ook van jou verwag word om 'n kort vooraf geselekteerde buitespoor langs die laboratorium te loop. Dit is 'n nie-tegniese enkelbaan wat vir ontspanningsroetes min of geen risiko's inhou nie. Daar sal van jou verwag word om jou eie roete-skoen te gebruik om maksimum gemak en minder beseringsrisiko te verseker tydens die versperring. Vir die kaalvoetproef sal die loopband sowel as die CAF-laboratorium voor die aanvang van die studie gevee en skoongemaak word ten einde veilige en skoon loopomstandighede vir die blootgestelde voet te verseker. Jy kan ook vertr oud wees met die minimalistiese sandaal om 'n gemaklike veterspatroon te bepaal. Alle toerusting wat gebruik word, sal nie indringend wees nie e n sal op die spesifieke benerige landmerke (enkels, knieë, heupe, lumbale ruggraat en torakale rug) gebind w ord deur sagte skuimbande te gebruik.

As jy nie instem om deel te neem nie, watter alternatiewe het jy?
As deelnemers nie daartoe instem om deel te neem nie, kan hulle die studie verlaat of verkies om in geselekteerde studies of 'n alternatiewe navorsingsprojek deel te neem, waar hulle tot die voorwaardes instem.
Alhoewel dit onwaarskynlik is,
wat sal gebeur as jy op een of ander manier beseer word omdat jy aan hierdie navorsingstudie deelgeneem het?

Agtergrond inligting:

- *Die borg van 'n verhoor moet toesien dat die deelnemers aan gesondheidsondersoeke gedek word deur om vattende versekering in die geval van liggaamlike (liggaamlike) letsel of besering, insluitend die dood. Dit beteken da t die versekeringsmaatskappy 'n deelnemer sal vergoed vir mediese onkoste wat direk voortsp ruit uit hul deelname aan navorsing sonder dat die deelnemer moes bewys dat die borg die sk uld begaan het.*
- *Die Universiteit Stellenbosch het versekering om deelnemers te dek aan alle nie-bedryfsgeborgde navorsingstudies wat by die HREC geregistreer is.*

- *Dit is belangrik om aan elke deelnemer te verduidelik dat:*
   - *Deur in te stem om aan hierdie studie deel te neem, stem hy / sy saam dat die risiko bestaan dat die medisyne (s) of die prosedure vir die studie hom / haar skade kan berokken. As dit so is, sal die borg hom / haar vir sy / haar mediese uitgawes vergoed sonder dat die deelnemer hoef te bewys dat die borg die skuld begaan het.*
   - *Die deelnemer kan egter steeds aanspraak maak op emosionele pyn en lyding as hy / sy dit verkies.*
     In hierdie geval sal hy / sy moet bewys dat die borg nalatig was en nie alle redelike en voorsienbare stappe gedoen het om die besering of emosionele trauma te voorkom nie. Dit sal 'n aparte wetlike aangeleentheid wees.

Die Universiteit Stellenbosch word deur omvattende skuldlose versekering gedek, en sal enige mediese koste betaal wat vir persone veroorsaak is omdat hulle aan hierdie projek deelgeneem het (ongeag of hulle die medikasie vir hierdie proefneming gebruik het, en of hulle op ’n ander manier deelgeneem het). Skuldlose versekering beteken jy hoef nie te bewys dat die borg (die Universiteit) skuld het aan die gebeure wat die kostes vir jou veroorsaak het nie.

Sal jy betaal word om aan hierdie studie deel te neem en is daar kostes daaraan verbonde?
Daar is geen betaling vir deelname nie. Deelnemers sal egter 'n volledige verslag ontvang met die resultate van hul toetsing en 'n praktiese uiteensetting van wat hierdie resultate beteken. Nadat die toetsing voltooi is, kan deelnemers die geleentheid hê om 'n afspraak van 1 uur by een van die navorsers te bespreek.
In hierdie uur sal ons vrae beantwoord wat deelnemers het oor hul loopgang kinematika en advies aan hulle gee in 'n sportwetenskaplike hoedanigheid.

Is daar iets anders wat jy moet weet of doen?

- Jy moet jou huisarts of gewone dokter vertel dat jy aan 'n navorsingstudie deelneem. As jy gewaarsku word om aan 'n maksimale oefening deur 'n dokter deel te neem, kies dan om nie aan Emily se studie deel te neem nie.
- Jy moet ook aan jou mediese versekeringsmaatskappy sê dat jy aan 'n navorsingstudie deelneem.
- Jy kan die Komitee vir Gesondheidsnavorsingsetiek skakel by 021 938 9677/9819 indien daar nog iets is wat u studielid nie aan jou verduidelik het nie, of as jy 'n klag het.
- Jy sal 'n afskrif van hierdie inligting en toestemmingsvorm ontvang om jou veilig te hou.
- Deur hierdie verklaring te onderteken, stem u in om u data te bewaar en slegs onder die navorsingspan en u self te deel. Onder geen omstandighede sal data met iemand anders behalwe die STARR-groep en u self gedeel word nie. Data sal onder bewaring gehou word.

Besluit om deel te neem:
(Dui met 'n regmerkie aan watter navorsingsprojekte jy bereid is om deel te neem)

☐ Die akute kinetiese en kinematiese verskille tussen normale skoene, kaalvoet- en minimalistiese sandale wat gewoonlik in manlike ontspanningsroetes aangebied word – <u>Matthew Swart</u>

☐ Die verskil in hardloopgang kinematika tussen hoogs opgeleide en ontspanningsroetes hardlopers voor en na 'n moegheidstimulus – <u>Emily Robertson</u>
*** Hoogs opgeleide hardlopers mag slegs aan hierdie studie deelneem ***

☐ **Die verskille in die produksie van laer liggaamsspierkrag en gangveranderlikes tydens loopband en roete by o ntspanningsroete hardlopers– Oloff Bergh**

Verklaring deur die ondersoeker:

Ek *(naam)* ……………………………………………… verklaar dat:

- Ek het die inligting in hierdie document op ‘n eenvoudige en duidelike manier verduidelik aan
  - ………………………………
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- Ek is tevrede dat hy/sy sal alle aspekte van die narvorsing, soos hierbo bespreek, volledig verstaan.
- Ek het/ het nie ‘n tolk gebruik nie. (As ‘n tolk gebruik word, moet die tolk nie onderstande verklaring onderteken.)

Geteken by (plek) ....…........…………….. op (*datum*) …………....…… 2019.

Handtekening van die onersoeker Handtekening van die getuie

APPENDIX E

ETHICS APPROVAL LETTER

UNIVERSITEIT
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UNIVERSITY

Approval Notice

New Application

Project ID #: 10753
HREC Reference #: N19/07/078

Title**:** Differences in running gait kinematics between highly trained and recreational trail runners

Dear Prof Rachel Venter

The **Response to Modifications** received on 26/09/2019 11:42 was reviewed and **approved** by members of the **Health Research Ethics Committee (HREC)** via Minimal Risk Review procedures on 10/10/2019.

Please note the following information about your approved research protocol:

Approval date: 10 October 2019

Expiry date: 09 October 2020

Please remember to use your HREC reference number (N19/07/078) on any documents or correspondence with the HREC concerning your research protocol.

Translation of the consent document/s to the language applicable to the study participants should be submitted.

Please note that HREC reserves the right to suspend approval and to request changes or clarifications from student applicants. The coordinator will notify the applicant (and if applicable, the supervisor) of the changes or suspension within 1 day of receiving the notice of suspension from HREC. HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:

Please note a template of the progress report is obtainable on https://applyethics.sun.ac.za/Project/Index/17215 and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape
Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape
Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel:+27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and documents please visit:

https://applyethics.sun.ac.za/Project/Index/17215 If you have

any questions or need further assistance, please contact the HREC office at 021 938

9657.

Sincerely,

Melody Shana

Coordinator

Health Research Ethics Committee 1

National Health Research Ethics Council (NHREC) Registration Number:

REC-130408-012 (HREC1)·REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372
Office of Human Research Protections (OHRP) Institutional Review Board (IRB)
Number: IRB0005240 (HREC1)·IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects; *the South African Department of Health (200*6). Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa (2nd edition); *as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes andStructures (2nd edition).*

The Health Research Ethics Committee reviews research involving human subjects conducted or supported by the Department of Health and Human Services, or other federal departments or agencies that apply the Federal Policy for the Protection of Human Subjects to such research (United States Code of Federal Regulations Title 45 Part 46); and/or clinical investigations regulated by the Food and Drug Administration (FDA) of the Department of Health and Human Services.

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To: Emily Robertson
Stellenbosch University

Barbara Elias
Tel.: +49 (0) 711 8931 681
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