UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences
Department of Physiotherapy

Epidemiology, clinical characteristics, and associated injury risk factors among trail running race entrants in the 2021 Mac Mac Ultra

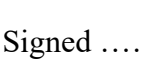
Submitted in fulfilment of the requirements for the degree
MPhysT

Mignette Jooste

Supervisor: Dr CT Viljoen (University of Pretoria)
Co-supervisor: Prof Christa Janse van Rensburg (University of Pretoria)
Prof. Volker Scheer (Ultra Sports Science Foundation, France)
Co-authors on published paper: Dr Audrey Janse van Rensburg (University of Pretoria)
Dr Dimakatso Ramagole (University of Pretoria)
Dr Tanita Botha (University of Pretoria)

DECLARATION

I, the undersigned, declare that the dissertation hereby submitted to the University of Pretoria for the degree M Physiotherapy and the work contained therein is my own original work and has not previously, in its entirety or in part, been submitted to any university for a degree.

Signed ……  ……. this ……. day of …20 September…2023

DEDICATION

To my husband, André

ACKNOWLEDGEMENT

I would firstly like to thank my supervisor Dr. Carel T Viljoen. Thank you for teaching me the meaning of research and for inspiring me to pursue research. Thank you for your support and understanding throughout this process, and for pushing me beyond my comfort zones. Your belief in me has not only helped me believe more in myself, but challenged me to bring the best that I can. I hope to continue to make you proud in the field of research.

Secondly, I would like to thank my co-supervisor and co-authors. Your diligence and support throughout the whole research and publication process is something I will forever be grateful for. It was an honour and absolute pleasure to work among such intellectual minds as yours.

I would like to thank my husband, you have always inspired me with your determination, work ethic and your truly inspiring way of life. Thank you for your unwavering support and for your motivation and encouragement. Without you this will not have been possible.

Lastly, I would like to thank my parents for always encouraging me to be the best version of myself, thank you for the opportunities that you have given me and for your unconditional support.

SYNOPSIS

Title: Epidemiology, clinical characteristics, and associated injury risk factors among trail running race entrants in the 2021 Mac Mac Ultra

Candidate: Mignette Jooste

Supervisor: Dr CT Viljoen

Co-supervisors: Prof. Christa Janse van Rensburg and Prof. Volker Scheer

Degree: M Physiotherapy

Background: There is limited research available on the epidemiology, clinical characteristics and associated injury risk factors in trail running. This gap in research may put trail runners at risk when competing in challenging trail running races.

Aim of the study: To determine the epidemiology, clinical characteristics and associated injury risk factors among trail runners entered in the 2021 Mac Mac Ultra Race.

Design: Retrospective cross sectional study

Setting: 2021 Mac Mac Ultra race, Sabie, Mpumalanga, South Africa

Participants: 251 consenting trail runners

Methods: Data gathered during the pre-event medical screening process include trail runners' demographics (BMI, height, age, running experience, weight), training variables in respect of running (weekly frequency, weekly distance, surface, average pace, shoes, vertical gain, cross-training,), injury history (clinical characteristics of injury, running-related injury (RRI) in the past 12 months, current RRI, severity of injury), history of disease (chronic disease, current illness) and usage of medication (current, chronic medication). Only the injury-related data were analysed in this study. The questionnaire is used in pre-race medical screening at various trail running events across South Africa. Race entrants self-report their injuries sustained in the past 12 months by responding "yes" to the question: "Did you sustain any running-related injuries in the past 12 months?". Runners currently injured had selected "injury" in response to the question: Do you have a current injury or illness? If "injury" was selected, then additional questions were posed in relation to the four main considerations of the Oslo Sports Trauma Research Centre Questionnaire on Health Problems (OSTRC-H) (Clarsen et al., 2013). To be recorded as a current injury, the race entrant had to indicate that training modification was needed during the two weeks before the race.

Furthermore, like the study on the 2019 Sky Run Race, questions that fixated on the clinical aspects of injuries were asked. We used the Pearson Chi square test to compare categorical variables of all athletes in the event versus consenting athletes in the event to establish if our

sample was representative of the population (all 2021 Mac Mac Ultra race entrants). Frequencies (n, %) of injury for pathology type, tissue type, body area and anatomical region utilised descriptive statistics. Inferential statistics (Independent t-test and Mann Whitney U test, and Chi Squared tests) were applied to contrast the training and demographic data of entrants between injured and non-injured entrants to examine and find connected injury risk factors. Odds Ratios were calculated using Binary logistic regression to investigate further the association between exposure and outcome (sustaining RRIs). Entrants were categorised into those who experienced a RRI during the previous 12 months vs. non-injured participants. Due to zero of the univariate examinations yielding statistically significant results ($p<0.05$), a multivariate evaluation was omitted.

Results: A total of 330 trail runners entered the race, although the questionnaire used at pre-race medical screening was compulsory, participation in the study was not, 251 out of the 330 race entrants gave consent to use their data. Twenty percent of trail runners stated one RRI or more. The retrospective annual incidence was 19.92/100 athlete-years. The point prevalence was 4.4%. Injuries mostly appeared in the lower limb (95%), including the lower leg (26%), thigh (22%), ankle and foot (13%) described as the highest injured body areas. Of tissue type injuries, muscle/tendon comprised 60%. Muscle injury (36%), tendinopathy (24%) and joint sprains (9%) were the most reported pathology types. No related injury risk factors were discovered in this study.

Conclusion: One in five trail runners reported one or more RRI during the 12 months before a competitive event. Running-related injuries commonly involved the lower limb, especially the lower leg, thigh, foot, and ankle. In this study no risk factors associated with sustaining a RRI was identified, this can be due to the complex nature of injuries.

Keywords: running-related injuries, clinical characteristics, trail running, epidemiology.

TABLE OF CONTENTS

LIST OF TABLES

Chapter 1

Chapter 3

LIST OF FIGURES

Chapter 1

Chapter 3

Chapter 4

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BMI	Body mass index
CI	Confidence interval
COPD	Chronic obstructive pulmonary disease
CVD	Cardiovascular disease
DOMS	Delayed onset muscle soreness
ECG	Electrocardiogram
EEE	Excessive endurance exercise
HCP	Healthcare professional
ITBS	Iliotibial band syndrome
ITRA	International Trail Running Association
OR	Odds ratio
OSTRC	Oslo Sports Trauma Research Centre
km	Kilometres
MTSS	Medial tibial stress syndrome
PFPS	Patellofemoral pain syndrome
RRI	Running-related injury
RRMI	Running-related musculoskeletal injury

Chapter 1

Introduction

1. Introduction

This chapter intends to offer information on trail running, trail running injuries and injury risk factors. In this chapter the problem statement, research question, aims and objectives of this masters study are discussed. It also covers the research design, assumptions and delineations as well as the significance of the study. It further contains the definition of key terms as well as a visible demonstration explaining the research strategy. This chapter concludes with an outline of each chapter as part of this thesis.

1.1 Background

Running recreationally is an effortlessly available means of exercise that plays an essential part in preventing lifestyle diseases and premorbidity (Strasser et al., 2013). Trail running as a classification of off-road running, embraces running in nature in numerous sorts of natural locations (forests, deserts, mountains, coastal regions and jungles/rainforests). Trail running is not limited by kilometres or altitude differences and transpires on diverse topographies (e.g. single track, forest trails, beach sand and dirt roads, etc.), restricting the volume of paved paths to 20-25% of the entire race (Scheer et al., 2020). Furthermore, the route is correctly demarkated by precise marks such as flags, arrows, badges, global positioning system (GPS) coordinates, boards, or map indication. Races on trails are customarily self-reliant, with contestants carrying apparatus, drink and food for themselves. Many ultramarathons (42.195 km races or more in distance) held on trails other than paved/tar roads meet the requirements to be defined as trail running (Scheer et al., 2020). Athletes running on trails are usually subjected to sizeable elevation variations because of running in rugged settings such as valleys and cliffs. While running positively influences health, an elevated risk of trail running related injury (RRI) still exists (Vernillo et al., 2016).

An injury incidence ratio of 0.7-61.2 injuries/1000 hours of running and a general injury prevalence percentage of 1.3-90% was stated by a living systematic review. The body zone most regularly injured in every study investigated included the hip, the ankle and the foot/toe. The most regular injury diagnoses reported were shallow tissue/epidermal injuries, injuries of muscle and tendon, ligament injuries and injuries of the joint capsule (Viljoen et al., 2022).

Regarding injury risk among trail runners, multiple extrinsic (disregarding a warm-up, not utilising a specialised training plan, double sessions a day, regular training on asphalt, as well as physical labour careers) and intrinsic factors (running experience, age) are described to have a substantial relation regarding injury amid trail runners (Viljoen et al., 2022). The studies

investigated in this living systematic review, looked at singular risk factors in the contexts of these studies, but limited associations were found for these risk factors among different settings of trail running. (Viljoen et al., 2022). Many trail run races, the Mac Mac Ultra race in South Africa included, are hosted in remote, isolated sites making it unreachable for vehicles with the only access for emergency medical teams being by foot (Hoffman et al., 2014). Trail running athletes who suffer an injury which end in failure to continue running, run the risk of being subjected to detrimental conditions and climate threats, while awaiting medical interventions (Hoffman et al., 2014). This necessitates the importance of improving the understanding of injury prevalence and injury profiles of runners with existing injuries entered and competing in an ultra-trail event, as the aggravation of injury in an ultra-trail event may have severe consequences (Roi, 2021). Increased insight could help race organisers and medical staff to prepare more proficiently in terms of readiness, managing and evacuation of trail runners on race-day. It is imperative to increase the knowledge regarding factors that are related to injury during the preparing phases before a trail run race. This will aid healthcare professionals (HCP) working with athletes and athletes competing in trail run races to lessen the chance of injury in the preparing phase of the trail run race.

The first aim of the research covered in this dissertation, was to analyse clinical characteristics, and epidemiology of RRIs amid race entrants entered for 2021 Mac Mac Ultra race in the two weeks prior the race as well as the 12 months period prior. We additionally planned to describe RRI risk factors, specifically, in trail running.

1.2 Problem statement

It is evident that trail runners are subjected to challenging terrains and extremely strenuous conditions. Although there are extensive sources on the epidemiology of RRIs and related injury risk factors in road running, a substantial lack of evidence and agreement on the epidemiology of RRIs and related risk factors amid athletes participating in trail running exist. It is important to have an enhanced understanding of trail running injuries and related injury risk factors to design and provide successful preventative strategies for managing and reducing RRIs in trail running.

1.3 Research question

What are the clinical characteristics, epidemiology, and related injury risk factors amid athletes participating in trail running who entered the 46km, 80km, 161km, and 322km race categories of the 2021 Mac Mac Ultra trail race?

1.4 Aims of the study

To establish the epidemiology (point-prevalence and retrospective annual incidence), clinical characteristics (type of pathology, type of tissue, anatomical region and body area) and related injury risk factors among runners participating in trail running and entered the 2021 Mac Mac Ultra race.

1.5 Objectives of the study

The study objectives were to:

1. Establish the retrospective annual incidence of injury, 12 months preceding the race, among 2021 Mac Mac Ultra race entrants – using a modified OSTRC questionnaire for data collection during a two-week period prior to the 2021 Mac Mac Ultra race.
2. Establish the point prevalence (current injury at the time of race registration) among 2021 Mac Mac Ultra race entrants – using a modified OSTRC questionnaire for data collection during a two-week period prior to the 2021 Mac Mac Ultra race
3. Establish the clinical characteristics of injury by recording the frequencies (n, %) of injury for anatomical sites, tissue types, specific RRIs - using a modified OSTRC questionnaire for data collection during a two-week period prior to the 2021 Mac Mac Ultra race.
4. Identify factors associated with injury in the main categories of demographics (age, sex, height, weight), training variables (weekly sessions of running, weekly running distance, running surface, running pace, cross-training, years of running participation, running shoes, elevation increase and decrease) and medical history, including injuries, using a baseline pre-race questionnaire as used in the recently published study on trail run race entrants in the 2019 Sky Run race.

1.6 Research approach

A quantitative research method was used. The data was from an existing dataset collected using an online pre-event medical screening questionnaire among trail running race entrants training towards the 2021 Mac Mac Ultra Race. Data collected from the participants was collected

cross-sectionally, with no follow-up. Ethical approval for the study was obtained (**Appendix A**), and permission for the researcher to use the data in this study was obtained (**Appendix B**).

1.7 Research design

The design used for this study was retrospective cross-sectional, to establish the epidemiology, clinical characteristics and related injury risk factors amid athletes, participating in trail running, who entered the 2021 Mac Mac Ultra race. Please refer to Figure 1 for the timeline of the study.

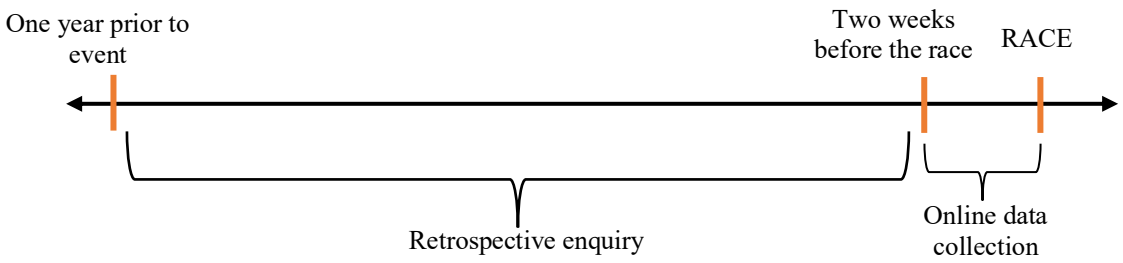


Figure 1: Timeline of research study

1.8 Importance and benefits of the study

As healthcare professionals, promoting participation in physical activity such as trail running to individuals to improve their overall health is important. However, participation in trail running can lead to injury, further leading to discontinuing physical activity (Viljoen et al., 2022). According to the literature, running injuries are sustained due to a combination of training errors and biomechanical imbalances (Nielsen et al., 2012). It is therefore necessary to detect any associated injury risk factors, describe predisposing factors in trail running, and inform trail runners about these findings. Investigating injury among runners training specifically towards the Mac Mac Ultra race will hopefully aid in assisting HCPs in better clinical decision-making regarding the design of future injury prevention strategies among Mac Mac Ultra race entrants. . It may also aid trail runners in preparation for these races. Additionally, it can further influence possible areas for future research studies.

1.9 Assumptions

As trail running takes place on demanding terrains such as mountainous or forest terrains, it is assumed that entrants predominantly trained on trails or similar terrains to that of the specific race in the 12 months preceding the race. Furthermore, it is assumed that self-reporting of participants' injuries will be honest and accurate.

1.10 Delineations

Only runners entered for the 2021 Mac Mac Ultra have been included in this study. The characteristics of a trail running race varies based on surface type, elevation changes, altitude, and weather conditions. Therefore, trail runners can follow different training programs depending on the type of race they are preparing for. Participants in this study trained for a certain race in a rough topography of the Mpumalanga province in South Africa. This study will, therefore, only report on this specific trail running population, and HCPs should consider this when generalising the results to trail runners preparing towards a different event.

1.11 Definition of key terms

Clinical characteristics: Training programs, previous injuries, medications, age, and sex etc., acquired through a compulsory online baseline demographic and injury profile questionnaire. In this study it refers to the frequencies (n, %) of injury for anatomical sites, tissue types, specific running-related injuries
(Andersen et al., 2013).

Epidemiology: Epidemiology refers to the study of the determinants, occurrence, and distribution of health and disease in a defined population**.** In the context of this study the epidemiological data will be reported according to point prevalence and retrospective annual incidence of trail running entrants entered for the 2021 Mac Mac Ultra race.

Odds ratio: The odds ratio (OR) is a measurement of how an occurrence is related with a specific exposure (Tenny and Hoffman, 2023a). The odds ratio is a proportion of two groups of probabilities: the odds of a RRI occurring in trail runners preparing for an event versus the odds of a RRI occurring in a non-exposed group.

Point Prevalence: " Prevalence" is the proportion of a population that has the characteristic at a specific point in time. Period prevalence is the proportion of a population that has the characteristic at any point during a given time period of interest. "Past 12 months" is a commonly used period." (Tenny and Hoffman, 2023b)

Retrospective Annual Incidence: According to Van Mechelen, W., Hlobil, H. & Kemper, H. C. (1992), injury incidence in sports uses the definition of: the amount of sports injuries per period being exposed (e.g. per 1000 hours of participation in sports) (van Mechelen et al., 1992). In this study it is defined as RRI/100 athlete-years. Retrospective annual incidence in

this study therefore refers to the number of injuries looking back over the past year and currently.

Risk factors: Any variable with an increased risk, in this study it refers to variables associated with and increased risk to sustain a running-related injury.

Tendinopathy: Pathology of a tendon that will cause pain as well as impaired function. Literature shows that this is common injury runners are exposed to. Therefore, it should be acknowledged and well understood by researchers since trail running and injury are key aspects of the study (Dias Lopes et al., 2012, Scheer and Murray, 2011).

Trail running: A form of running over mountainous and forest trails with alternating inclines. It is the sport or topic of interest to be studied and reviewed (ITRA, 2023).

1.12 Research process

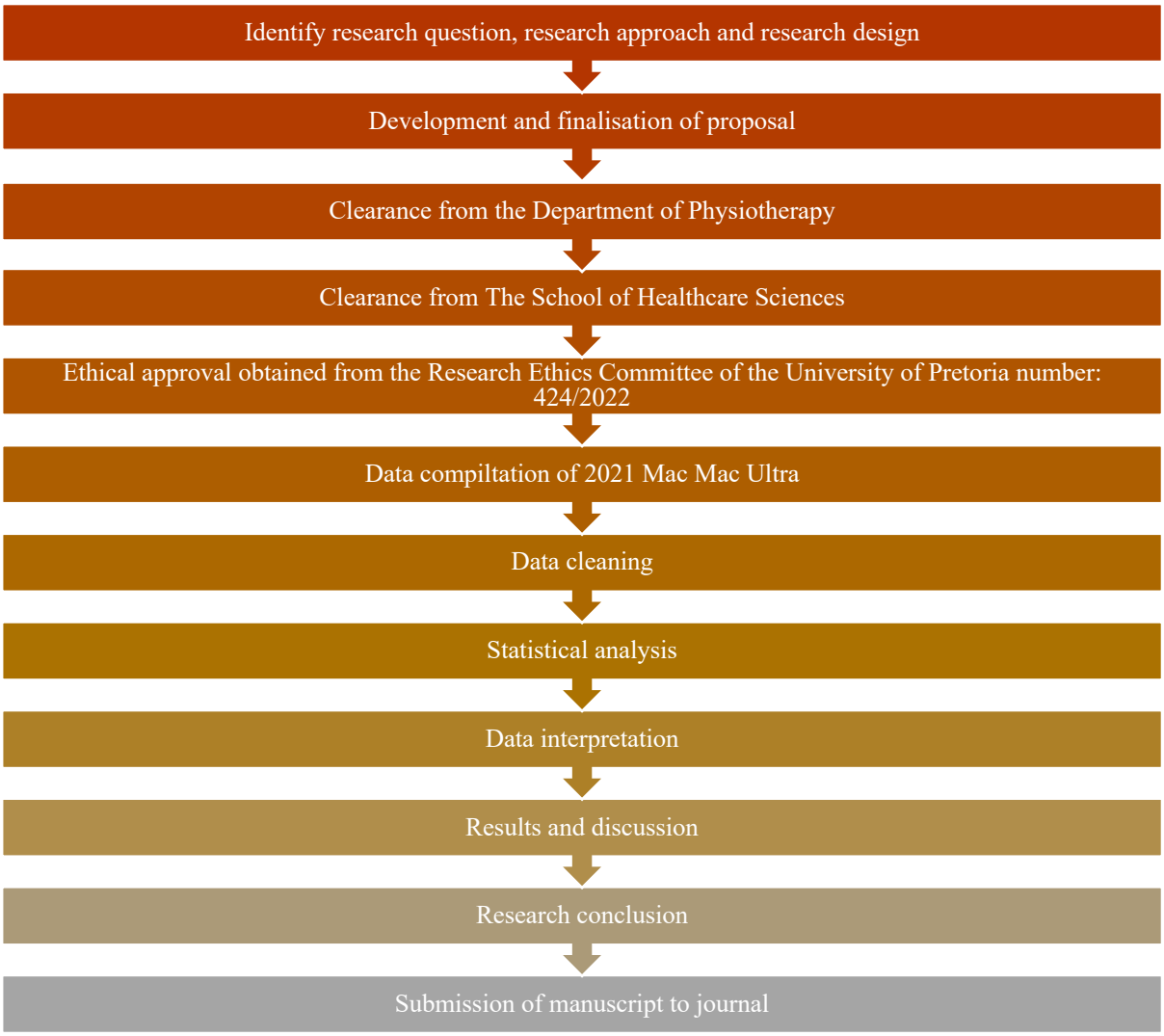


Figure 2:Flow diagram of the research process followed

1.13 Dissertation outline

Chapter 2 will focus on a literature review regarding the clinical characteristics, epidemiology, and related risk factors of road running compared to trail running.

Chapter 3 consists of a research article as published in an academic journal. It explores the clinical characteristics, epidemiology, and related risk factors of RRIs in the 2021 Mac Mac Ultra race entrants.

Chapter 4 will include a discussion of the main findings in chapter three, limitations and strengths, clinical and research recommendations, as well as concluding statements based on the findings of chapter three.

Table 1 demonstrates where the aims and objectives of this study was completed in the various chapters, as approved by the Faculty of Health Sciences Research Ethics Committee at the University of Pretoria.

Table 1: Aims and Objectives completed according to the chapters of the dissertation

	Chapter 2	Chapter 3	Chapter 4
Aim		x	
Objective 1		x	
Objective 2		x	
Objective 3		x	
Objective 4		x	

1.14 References

Andersen, C. A., Clarsen, B., Johansen, T. V. & Engebretsen, L. 2013. High prevalence of overuse injury among iron-distance triathletes. *British Journal of Sports Medicine,* 47**,** 857-861.

Hoffman, M., Pasternak, A., Rogers, I., Khodaee, M., Hill, J., Townes, D., Scheer, B., Krabak, B., Basset, P. & Lipman, G. 2014. Medical Services at Ultra-Endurance Foot Races in Remote Environments: Medical Issues and Consensus Guidelines. *Sports Medicine,* 44**,** 1055-1069.

ITRA (2023) International Trail running Association. Available at: https://itra.run/About/History (Accessed: 28 August 2023).

Nielsen, R. O., Buist, I., Sørensen, H., Lind, M. & Rasmussen, S. 2012. Training errors and running related injuries: a systematic review. *Int J Sports Phys Ther,* 7**,** 58-75.

Roi, G. S. 2021. Fatal Events Related to Running Competitions in the Mountains. *Wilderness Environ Med,* 32**,** 176-180.

Scheer, V., Basset, P., Giovanelli, N., Vernillo, G., Millet, G. P. & Costa, R. J. S. 2020. Defining Off-road Running: A Position Statement from the Ultra Sports Science Foundation. *International Journal of Sports Medicine,* 41**,** 275-284.

Strasser, B., Siebert, U. & Schobersberger, W. 2013. Effects of resistance training on respiratory function in patients with chronic obstructive pulmonary disease: a systematic review and meta-analysis. *Sleep & Breathing = Schlaf & Atmung,* 17**,** 217-226.

Tenny, S. & Hoffman, M. R. 2023a. Odds ratio. *Statpearls.* Treasure Island (FL): StatPearls Publishing Copyright © 2023, StatPearls Publishing LLC.

Tenny, S. & Hoffman, M. R. 2023b. Prevalence. *Statpearls.* Treasure Island (FL): StatPearls Publishing Copyright © 2023, StatPearls Publishing LLC.

Van Mechelen, W., Hlobil, H. & Kemper, H. C. 1992. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Med,* 14**,** 82-99.

Vernillo, C., Savoldelli, A., La Torre, A., Skafidas, S., Bortolan, L. & Schena, F. 2016. Injury and Illness Rates During Ultratrail Running. *International Journal of Sports Medicine,* 37**,** 565-569.

Viljoen, C., Janse Van Rensburg, D. C. C., Van Mechelen, W., Verhagen, E., Silva, B., Scheer, V., Besomi, M., Gajardo-Burgos, R., Matos, S., Schoeman, M., Jansen Van Rensburg,

A., Van Dyk, N., Scheepers, S. & Botha, T. 2022. Trail running injury risk factors: a living systematic review. *British journal of sports medicine,* 56**,** 577-587.

Chapter 2

Literature Review

2. Literature review

2.1 Introduction

Trail running is an increasingly prevalent sport. However, there is a lack of research on this division of running. The current limited published literature restricts the ability of healthcare professionals and trail runners to design adequate injury prevention strategies. This chapter includes a literature review on the clinical characteristics, epidemiology, and associated injury risk factors amid trail running participants. An outline of exercise and the positive influences thereof is discussed, followed by an overview of running as a part of exercise. Trail running is then compared to road running to provide an understanding of the different demands between the two modes, after which trail running as a mode of running is presented. Lastly, a comprehensive discussion of all available research on trail running injuries and the associated risk factors is included. Currently, there are three recently published reviews (a systematic review, a living systematic review, and a narrative review) that cover the topics of injury, injury risk factors, injury prevention tactics, and rehabilitation considerations in trail running (Vincent et al., 2022, Viljoen et al., 2021c, Viljoen et al., 2022). Therefore, this chapter is presented as a literature review for the purpose of this dissertation and won't be submitted for publication considering the context of the available current literature.

2.2 Search strategy

An electronic investigation was performed in October 2021. Towards the end of my Masters process, I updated the search in August 2023. The University of Pretoria's library was used to search the following databases: CINAHL: Cumulative Index to Nursing and Allied Health Literature, Academic Search Complete, African-Wide Information, Health Source: Consumer Edition, Health Source: Nursing/Academic Edition, MEDLINE, and SPORTDiscuss. The key terms used during the literature review were: "physical activity", "running", "trail running", "physical demands", "running-related injuries", and "injury risk factors".

2.3 Benefits of exercise

Exercise can be labelled as "any bodily movement produced by skeletal muscles that results in energy expenditure" (Caspersen et al., 1985). According to a review by Lee J., Shiroma E., Lobelo F., (2012), globally, inactivity causes 6% of all illnesses influencing the coronaries in the heart, 7% of diabetes type 2, 10% of breast cancer and 10% of cancer found in the colon. Furthermore, the study states that 9% of all-cause pre-morbidity globally is due to sedentary lifestyles (Lee et al., 2012). Exercise has many beneficial effects on multiple diseases,

including cardiovascular disease (CVD), diabetes mellitus and cancer (Sharif et al., 2018). Exercise performed at moderate to vigorous intensities was found to reduce blood pressure (BP) improve cardiorespiratory fitness (CRF) and reduce the incidence of hypertension (Bakker et al., 2018). Aerobic exercise and resistance training can improve respiratory performance in individuals suffering from Chronic Obstructive Pulmonary Disease (COPD). It may eliminate risk factors such as obesity, elevated sugar levels and systolic blood pressure in patients diagnosed with metabolic syndrome (Strasser et al., 2010). A systematic review investigating women's reproductive health functions among polycystic ovarian syndrome found that regular physical activity positively influenced menstrual cycles, ovulation, overall fertility, and social and psychological stress (Butt et al., 2023).

Exercise also plays an imperative part in mental well-being, according to a study done by Mikkelsen et al. (2017), which found some psychological effects of exercise may involve a decreased sense of depression and stress and lead to an increased self-esteem. The researchers stated that only 20–40 min of aerobic exercise can positively influence mood and anxiety for numerous hours (Mikkelsen et al., 2017). Another study looking at mental well-being and the benefits of physical activity found that exercise can significantly reduce depression severity, improve life gratification, positively influence moods and give people a better awareness of purpose and life meaning, ultimately reducing the negative influences of depression on people's work life (Li et al., 2022). Many forms of exercise exist, with running being one of them.

2.4 Running

Running is a well-liked and convenient form of exercise that substantially influences life expectancy. A review done by Lee et al. (2017), stated that people participating in running have a 30-45% smaller risk for all-cause death, the risk for CVD-related death is lessened by 45%-70%, and there also a 30-50% lesser risk of cancer-related death compared to non-runners. The study further states that running may be reduce mortality stemming from diseases with neurological involvement, such as Parkinson's Disease and Alzheimer's, as well as respiratory infections. These mortality benefits appeared steady irrespective of age, sex, BMI, health disorders and alcohol consumption. Lastly, the study found that runners had a 3.2 year longer life expectancy than the non-active population.(Lee et al., 2017). Another study reported that recreational running resulted in a 28% lesser risk for developing a chronic condition such as type 2 diabetes, equated to non-runners (Wang et al., 2019).

Although running has a significant impact on all-cause mortality (CVD, obesity, hypertension, diabetes, and hypercholesterolemia), Lee et al. (2017) also found that excessive endurance exercise (EEE), such as persistent running may negatively influence cardiac function and structure, including structural variations in the heart and its autonomic control, myocardial fibrosis, inflammation and added vascular oxidative stress (Lee et al., 2017).

Running is a convenient and fashionable mode of exercise and significantly influences the reduction of all-cause mortality and can improve overall mental health. Various running divisions exist, of which trail running is one, referring to running primarily on non-paved terrains.

2.5 Trail running

Trail running is a running division with similar health benefits to road running. Trail running is labelled as a race on foot in natural settings, including forests, mountains, coastal areas, deserts, rainforests/jungles or grass. It occurs over several different terrains, including single track, beach sand, dirt road, forest trail, etc. The race consists of minimal paved or asphalt roads, with a maximum of 20-25% of the complete race (Scheer et al., 2020). There are no restrictions in distance or vertical displacements, the route is properly marked (flags, tapes and signs), and runners may use map indications or global positioning systems (GPS) (Scheer et al., 2020). The race is self-sufficient regarding clothes, communication, food and drink. There are usually aid stations along the route. Race organisers may recommend compulsory safety equipment and rules to reduce risks and ensure the safety of runners and officials (Scheer et al., 2020).

Trail running is further defined as an endurance event with varying terrain and altering climbs and descents, resulting in elevation gain and loss. Races can be completed in one stage or multi-day stages. Stage races are increasingly prevalent, often in challenging terrains (Scheer and Murray, 2011). Trail running races range from a few kilometres to well beyond 80 km in ultra-trail races. The distance, challenging terrain and elevation changes all add to the difficulty of the race. In 2013 the International Trail Running Association (ITRA) was found, and in 2015, World Athletics recognised trail running as a division of athletics. In 2018, ITRA implemented a categorisation system, grouping trail races by “km-effort”, regarding race distance and vertical gain. Furthermore, according to ITRA, trail running has been increasing in prevalence

at a rate of 15% per year from the mid-1990s. They estimate about 20 million trail runners worldwide are actively participating in the sport (ITRA, 2023).

In South Africa, between 2011 to 2016, there was a threefold growth in the amount of long-distance trail running events. The increase in events indicates the major growth potential of trail running in South Africa. According to a quantitative online survey by McKay, McEwan, Baker, (2019), 27% of respondents reported participating in nine or more trail running events in one calendar year. Seventy-three percent of the respondents reported participating in an event longer than 21 km (McKay et al., 2019).

In conclusion it follows that trail running is a relatively new mode of running as a sport, with an exponential growth rate. Trail running is considered specifically challenging due to extreme vertical displacements, weather and altitude changes, consistently requiring the body to adapt to the different displacements (Scheer et al., 2020), placing several physical demands on the trail runner's body.

2.6 Physical demands of trail running

Trail running requires different demands from a runner's body, compared to road running, due to the altering terrains and more challenging environments in which trail running events occur (ITRA, 2023). Road running is mainly run on paved roads made from asphalt or concrete and thus requires decreased effort to run at a constant pace and less energy expenditure to run at increased speeds (Dixon et al., 2000). A study by Dixon et al. (2000) suggests that to maintain a constant impact force on a stable surface, the body compensates by altering its running kinematics and causes increased lower extremity compliance, which can lead to more overuse injuries. This is possibly due to increased mechanical stiffness (Dixon et al., 2000).

The nature of trails demands the runner to react swiftly and adapt to roots, water, rocks, unexpected creatures, sharp turns and fallen trees/branches. The steep declines on trails utilise eccentric muscle contractions to produce a response against the force of gravity (Chen et al., 2008). This results in increased levels of myoglobin release in skeletal muscle (Le Goff et al., 2016). Myoglobin is a marker of muscle cell damage that presents as Delayed Onset Muscle Soreness (DOMS). The Bazgir et al. (2015) study found similar results as the Le Goff et al. (2016) study, and the results suggest a higher IL-15 serum level in athletes after eccentric resistance exercise compared to concentric resistance exercise. Eccentric contractions cause

micro-tears due to IL-15 secretion following extensive eccentric contractions, ultimately causing DOMS as mentioned above (Bazgir et al., 2015).

Trail running requires various planes of movements to achieve the ultimate foot positioning. Thus, an increased amount stabiliser muscles are activated than in road running, which results in delayed onset of muscle fatigue in the mobiliser muscle groups. This recruitment of additional muscles increases the oxygen demand, thus requiring increased CRF compared to road running. As a result of the constant changes in muscle group activation to sustain dynamic stability, certain muscle groups will be more depleted than others, resulting in muscle imbalances. Major muscle imbalances reduce the body's proficiency to react and acclimatise to the terrain quickly and may result in unwanted injuries (Stasulli, 2016).
Adverse weather can cause dangerous running conditions, such as decreased visibility, slippery wet terrains and concealed rocks, roots and holes (Stasulli, 2016). Extreme environmental conditions with increased temperatures can severely limit the heat loss necessary to maintain homeostasis and can cause thermoregulatory strain due to dehydration (Jarver and Cheuvront, 2002). It is important that the metabolic heat produced during exercise is transferred from the body as it can limit running performance (Jarver and Cheuvront, 2002).

In summary, concentric and eccentric muscle contraction combined with the technicality of terrains and unexpected weather conditions seen in trail running places increased demands on a trail runner compared to road running (Bazgir et al., 2015). This would result in a different RRI profile than commonly seen in road running. Running has a beneficial effect on health but presents with a high risk of sustaining running-related injuries (Kemler et al., 2018).

2.7 Running- related injuries and injury risk factors

According to a study by Kemler et al. (2018), new runners had an increased injury incidence compared to experienced runners. They found that from 2011 to 2013, the average four-year injury incidence for beginner runners was 8.78 per 1000 hours of running matched to 4.24 per 1000 hours for proficient runners. Their study also found that the most common location for injury in all groups was the knee, with a four year injury incidence average of 30.7 per 1000 hours of running in all runners, 31.1 per 1000 hours of running in the beginner group and 30.5 per 1000 hours of running in the cluster of experienced runners. They also found a noteworthy difference in the four year average of reported Achilles tendon injuries between experienced and beginner runners (8.4% and 2.3%, respectively) (Kemler et al., 2018). Their findings

showed an injury incidence of 2.5 times higher than all sports participants (5.11 vs. 1.97 per 1000 sport hours), showing that running is a high-risk sport for injuries (Kemler et al., 2018).

There is an increased risk of sustaining a RRI after rapidly increasing running distance between two weeks or general changes in training variables such as velocity, distance, volume or frequency. (Damsted et al., 2018). Additionally they found that generally females have a lessened risk for RRIs compared to men. However, they found that the following variables raised the risk of sustaining RRIs for females included older age, previous partaking in non-axial activities such as swimming and cycling, running on paved surfaces, running further weekly distances between 48-63.8km, as well as wearing specific shoes for four to six months. Men had a higher risk for injury if they started running again, had a history of former injury, had no more than two years of experience in running, and had a running distance between 32-47.8km per week or more than 64km per week (van der Worp et al., 2015).

A study determining the incidence and prevalence of lower limb injuries in male athletes participating in running found that 54.8% of the partakers sustained one or more RRI 12 months preceding the Rotterdam marathon. One month before the race 26.9% of partakers had an RRI, and 18.2% reported a new injury related to running, suffered during or directly after the marathon. Seventy-nine-point-six percent of these RRIs were reported as injuries sustained during training efforts (Van Middelkoop et al., 2008). The injury prevalence rate was 3.2 per 1000 hours of running. The lower limb was the most common injury reported, the knee included 30.7% of all injuries, then the calf (23.2%), and then the ankle at 14.6% (Van Middelkoop et al., 2008). The incidence of lower leg RRIs in runners who started the marathon was 18.2%, where the most common injury was the calf (33.9%), then the knee (27.1%) and then the thigh (17.8%). These findings are similar to Kemler et al. (2018).

A study on the incidence and prevalence of main RRIs, refers to RRIs as running-related musculoskeletal injuries (RRMIs). Out of the eight studies reviewed, 28 separate RRMIs were reported. The study first analysed general RRMIs sustained during training and found the following results: out of 21 general RRMIs reported during training, the most prevalent RRMI identified was Medial Tibial Stress Syndrome (MTSS), with an incidence rate between 13.6 and 20.0 per 1000 hours of running and a prevalence rate of 9.5%. The study stated that MTSS can develop due to the landing and toe-off phases, which stress the tibia, causing inflammation of the periosteum. Other potential risk factors for MTSS include a greater knee varus, frequent

changes in running shoes and interval training. Achilles tendinopathy followed MTSS with an incidence rate ranging from 9.1 and 10.9 per 1000 hours of running and a prevalence rate ranging from 6.2% and 9.5%. The third most frequent RRMI was plantar fasciitis, with prevalence rate between 5.2% and 17.5%. and an incidence rate between 4.5% and 10.0%. The RRMI with the highest incidence rate was patellar tendinopathy at 22.7 per 1000 hours of running. This is noteworthy as patellar tendinopathy was more commonly reported by leisure runners aiming to run distances between 20km to 50km and scarcely reported by marathon or ultramarathon runners. The review reported no clear relation between running performance and the reduced onset of tendinopathies, but there is an increase in acute onset tendinopathies seen in runners competing in ultramarathons that usually continue for five to eight consecutive days (Dias Lopes et al., 2012).

When Lopes et al. (2012) reviewed the research on the prevalence of RRMIs reported during an ultramarathon race, they identified Achilles tendinopathy as the most reported RRMI, with a prevalence rate ranging from 2.0% and 18.5%, and then patellofemoral pain syndrome (PFPS) with a prevalence rate between 7.4% and 15.6%. According to the literature reviewed in this systematic review, a main source considered in the development of tendinopathies is repetitive and excessive tendon loading as seen in running. Excessive loading predisposes runners to develop RRMIs such as Achilles tendinopathy. One study they reviewed mentioned that beginner marathon runners, using medicine, and only running a few kilometres a week were all risk factors for developing PFPS. Furthermore, compressive loading in the patellofemoral joint may also predispose runners to PFPS (Dias Lopes et al., 2012). The review concluded that various RRMIs observed are related to overuse and that the RRMIs were primarily below the knee. This is constant with other studies stating that the most common anatomical area for RRMIs is lower than the knee. In contrast, to several studies that found the knee as the most frequent site of injury, Lopes et al., (2012) did not have similar findings, as the knee did not have the highest injury prevalence or incidence rate of the overall RRMIs reported with training. This systematic review concluded that common anatomical regions for RRMIs are the foot, ankle, shin, and knee (Dias Lopes et al., 2012). This difference may be that studies took place in different geographical settings with different populations studied training on different surfaces as available due to their specific locations.

In a study where 36 studies were reviewed, aimed to establish the percentages of running injuries at various anatomical percentages and state the type of pathology where possible.

According to the anatomical area, the injury percentages were determined from 10 688 injuries described by 18 195 runners in the 36 studies. It was subcategorised by gender: women accounted for 2 279 injuries from eight studies and males 1 875 injuries from seven studies. The overall percentages for pathology types were estimated from 3 580 injuries by 4 752 runners (n=11 studies, also subcategorised by sex) (Francis et al., 2019). When looking at the injury percentages by anatomical area, they found the following results: the ankle/foot and knee and areas consisted of more than half of the injuries described at 28% and 26% respectively. The shank, the area between the knee and the foot, accounted for 16% of injuries reported. Thus, the data reviewed indicates that 70% of all injuries described were at the knee or below. The thigh and hip only consisted of 14% of the injuries reported. Injury proportions between men and women differed at the knee, foot/ankle and shank, where women mostly reported knee injuries at about 40% of reported injuries, then the ankle/foot (19%) and the shank (calf) (16%). The injuries reported by men were more evenly distributed, with the knee accounting for 31%, the foot/ankle for 26%, and the shank (calf) at 21% of reported injuries (Francis et al., 2019). The study further looked at running injuries according to specific pathological types and found that the two most regular running injuries were PFPS and Achilles tendinopathy, which supports previous literature on the prevalence of RRIs. They found that the proportion of PFPS is much higher than that of Achilles tendinopathy at 17% vs. 10%, and they further state PFPS may be gender biased towards women, as women have more knee injuries. Similarly, the proportion of ankle/foot injuries was higher for the men, indicating that the percentage of Achilles tendinopathy may be male-biased (Francis et al., 2019).

Fifty percent of runners sustain an injury in 12 months that keeps them from running, and 25.0% of runners are injured at any time (Kakouris et al., 2021). Seventy to eighty percent of RRIs are overuse injuries and most commonly below the knee, foot/ankle and shank anatomical sites. When looking at non-ultramarathoners, 75.3% of all injuries were in the following anatomical regions: the knee, followed by the lower leg, ankle and foot/toes. For ultramarathoners, lower leg, ankle, and knee were the most common body area injured, followed by the lower back, hip/groin and foot/toes. No significant variation in incidence percentages for ultramarathoners and non-ultramarathoners in regards to anatomical region of injury were recognised by monitoring specific pathology types between ultramarathoners and non-ultramarathoners. When looking at the prevalence of ultramarathoners, PFPS had the greatest prevalence percentage of RRMI, and MTSS had the highest prevalence rate (35.0%). PFPS and stress fractures were the most commonly reported RRMI. The pathology type, among

the non-ultramarathoners, with the greatest incidence percentage was Achilles tendinopathy (10.3%), and for ultramarathoners, the greatest injury percentages were anterior compartment tendinopathy (19.4%). The greatest incidence rate for a RRMI in non-ultramarathoners was patellar tendinopathy (22.7%) and PFPS (41.7%) in ultramarathoners. In conclusion, the most commonly reported RRMI seen with the non-ultramarathoners were Achilles tendinopathy and plantar fasciitis, and seen with ultramarathoners, the most commonly stated RRMIs included anterior compartment tendinopathy, PFPS and Achilles tendinopathy (Kakouris et al., 2021).

A systematic review of biomechanical risk factors related to RRIs, reviewing 15 studies, concluded that biomechanical variables have inconsistent findings and that the findings mainly depend on the populace and injuries investigated. They further conclude that further research is required to confirm if these variables are indeed risk factors and if amendment may assist in managing and preventing RRIs (Ceyssens et al., 2019). Another systematic review on biomechanical risk factors for sustaining RRIs in different running populations found that aspects such as level of competition, gender and foot strike may impact biomechanical variables related to RRIs. Also, hip adduction and decreased ankle/rearfoot eversion may likely act as risk factors for sustaining a RRI in female leisure runners who predominantly adopt a rearfoot strike pattern. Similar to the findings of Ceyssen et al. (2019), continued efforts are needed to pinpoint biomechanical risk factors and guide injury prevention (Vannatta et al., 2020). A systematic review from Raghunandan et al. (2021) investigated intrinsic and extrinsic risk factors in endurance running and found that intrinsic risk factors including previous injury history, especially during the last 12 months, have shown to be a risk factor for potential injury, which coincides with existing literature. Other intrinsic risk factors include runners with an increased BMI or abnormal nutritional status, such as runners with the female athlete triad. These athletes usually have decreased bone mineral density, placing them at increased risk for bone stress injuries. Other intrinsic risk factors related to running biomechanics include peak ankle/rearfoot eversion, peak hip adduction, foot strike pattern and vertical load rate. However, they support the Ceyssen et al., 2019 study, stating that the evidence is inconsistent. They further stated that findings vary per population. For example, female athletes with increased peak hip adduction were at a greater risk of developing PFPS and iliotibial band (ITBS) syndrome. These findings, however, are not duplicated in mixed-gender cross-country populations (Raghunandan et al., 2021). Other kinematics, such as femoral internal rotation, greater knee abduction, and knee stiffness, may also contribute to injury. Decreased flexion at the knee joint may increase the risk for Achilles tendinopathy in leisure runners due to

increased loading of the calf and tendon. Other studies showed that lower step rates in female runners may contribute to MTSS, but the literature is conflicting. The study concludes that although joint biomechanics are a factor in developing RRIs, the results are inconsistent and often in contrast with one another (Raghunandan et al., 2021). They further mention the possible extrinsic factors contributing to sustaining a RRI. These include training errors, increased running distances and increased training intensities. One study showed that when looking at runners 60.0% of men and 50.0% of women with an injury multiplied their training distance by more than 30.0% in the few weeks before sustaining an injury. Furthermore, they found that race distance was a substantial risk factor for sustaining an injury. Runners who entered for a 42km race were three times more likely to develop an injury than runners who entered for a 10 km race distance. As seen in previous literature, a previous RRI had the highest odds ratio for sustaining an injury (Raghunandan et al., 2021).

According to a study done on multifactorial determinants on injury locations in recreational runners, Achilles tendinopathy was found to be associated with midfoot strike patterns, and posterior lower leg (mostly calf injuries) injuries were found to have an association with forefoot strike patterns. This is due to the extra stress placed on the calf muscle with a forefoot strike pattern (Hollander et al., 2021).

Extensive research exists on the epidemiology of road running-related injuries and related injury risk factors. As previously discussed, trail runners are subjected to different environmental and musculoskeletal demands. Therefore, we expect the injury profile of traditional road running to differ from trail running.

As seen in section 2.7, there is extensive literature on the prevalence and incidence RRIs, as well as risk factors contributing to sustaining RRIs. However, limited information on trail running-related injuries and risk factors associated with sustaining injuries is available. Trail running injuries will be discussed in this section, followed by trail running risk factors for sustaining RRIs.

2.8 Trail running injuries

A study by Malliaropoulos et al. (2015) on the prevalence of injury in ultra-trail running, determined musculoskeletal (MSK) injuries in 40 ultra-trail runners by recording injuries and associated symptoms. Data was collected using a questionnaire developed by physiotherapists.

Participants completed the questionnaire after completing the race. The results showed that 36 participants (90.0%) of the runners complained of a minimum of one RRI (Malliaropoulos et al., 2015). Overuse injuries accounted for 82.2% (n=111) of the reported injuries, and 17.7% (n=24) appeared during the race (Malliaropoulos et al., 2015). According to the results, the lower back was reported as the most injured anatomical area, with a prevalence of 43%, trailed by the knee, with a 40.0% prevalence (Malliaropoulos et al., 2015). A possible justification may be that throughout uphill running, the trunk of the body is in a sustained forward position. Hence, this leaning may cause a shortening of the hamstring muscle complex (Easthope et al., 2010), this then can result in a change in runner's biomechanics such as position of the pelvis, causing more strain on the lower back causing pain. Achilles tendinopathy was reported as the anatomical region with the greatest percentage of injury severity, followed by the lower back (Malliaropoulos et al., 2015). After reviewing this data, restrictions to the study may include the small sample size (40 participants), of which only four were female, and all participants were local to Greece. This makes it challenging to generalise the findings to the international trail running community (Malliaropoulos et al., 2015). Additionally, Malliaropoulos et al., (2015) excluded ankle injuries due to recall bias, resulting in inaccurate reporting of all trail running-related injuries that occurred during the race. Despite the evident limitations, it is noteworthy that 90% of the runners still sustained a RRI (Malliaropoulos et al., 2015).

A study by Scheer et al. (2011) reported observations of medical interventions during the Al Andalus Ultra Trail, a 219-km, 5-day ultramarathon stage race hosted in Southern Spain (Scheer and Murray, 2011). It is the first study on various injuries and ailments in a multistage ultramarathon where medical support was continuously available (Scheer and Murray, 2011). Participants were offered medical attention on request at any stage of the race. Sixty-nine runners recorded 99 medical interventions. They reported that the most common injury was blisters (26.1%), in line with other literature. Other injuries and illnesses included exercise-associated collapse, fatigue and vomiting (Scheer et al., 2011). The most common MSK complaints included knee injuries, affecting five runners who sustained PFPS (7.2%) resulting in one participant having to retire (Scheer et al., 2011). This is reinforced by other literature as the knee is the most injured anatomical region in endurance runners. Other injuries involved the: tendinopathy of the ankle dorsiflexors (ultramarathoner's ankle), Achilles tendinopathy, trochanteric bursitis, muscular pains, and ankle inversion injuries (Scheer et al., 2011). One limitation to the study may be that, because many participants are well acquainted with the sport, only the runners experiencing continuous, severe and bothersome symptoms will report

to the medical team, therefore injuries may have been underestimated and inaccurately reported (Scheer et al., 2011).

A prospective open cohort study by Hespanhol Junior, van Mechelen and Verhagen, (2017) researched Dutch trail runners partaking in trail running in the Netherlands. They looked at the health and economic problems of RRIs. They used an online questionnaire to enquire about the prevalence, injury rate, nature, severity and economic strain of running-related injuries of Dutch trail runners. Two hundred and twenty-eight trail runners partook in this study, 171 males and 57 females, respectively. All participants were monitored for at least six months. The results indicate that trail running injuries with an abrupt onset are less likely to occur than overuse gradual injuries due to repetitive microtrauma (Hespanhol et al., 2017).

Two weeks after the race, all participants received follow-up questionnaires to be completed via email. According to the follow-up questionnaire, 242 running-related injuries were reported amongst 148 participants. Of these 148 participants, 45.9% reported multiple RRIs (Hespanhol et al., 2017). Overuse injuries were more regularly reported than acute injuries. Furthermore, more males were injured compared to females, 23.0% and 20.7% respectively (Hespanhol et al., 2017). The most frequently reported RRIs were Achilles tendinopathy at 12.8 %, calf muscle injury at 10.7 %, and vague knee pain at 8.7 %. These results coincide with other literature that lower limb MSK injuries are commonly found among trail runners. The least reported injury was ankle sprains at 7.0%, much lower than a study done by Vernillo et al. (2016) where ankle sprains were reported at 28.6%. A limitation of this study is that the results by Hespanhol et al., (2017) cannot be generalised to the international trail running community events due to the specific landscape, reduced elevation and nature of the topography in the Netherlands. However, runners being followed up for six months increased the chance of recording delayed onset injuries or symptoms. This makes the study's results significant, compared to others where injuries were recorded cross-sectionally.

A study by Vernillo et al. (2016), determining injury and illness occurrences during ultra-trail running, reported on 77 runners partaking in a 65km trail run in Trento, Italy. The participants, who were predominantly experienced runners, completing multiple previous marathons, were invited to visit the medical tent regardless if they required medical assistance for an injury or illness. Participant's injuries were self-reported and recorded by medical staff within the first ten minutes of completing the race. Every medical encounter was grouped according to illness,

MSK or dermatological. One hundred and thirty two injuries/illnesses were seen during the race. Predominantly, medical encounters were minor and primarily due to general fatigue (37.7%) and muscle cramps (26.2%). Other studies on ultramarathon runners like (Krabak et al., 2011), found that MSK injury rates were lower (0.4–2.7 injuries per runner) when compared with the Vernillo et al., (2016) findings of 4.3 MSK injuries per runner (Krabak et al., 2011)
The differences among studies could be due to various aspects such as the environment, equipment, and reporting bias. Runners doing a multi-day race are required to carry more equipment, and are exposed to more extreme environments and varying temperatures for longer periods of time, which can result in discrepancies in injuries being reported, especially with regards to fatigue and exercises-associated collapse.
Vernillo et al. (2016) stated that MSK injuries accounted for 32.8% of all injuries/illnesses, and dermatological disorders for 16.9%. Plantar fasciitis (28.6%) and ankle sprain (28.6%) were the most prevalent MSK injuries reported (Vernillo et al., 2016). This can be due to the significant demands on these structures when running on uneven surfaces for long distances. Furthermore, blisters accounted for 53.8% of dermatological disorders reported. This may be due to repetitive combined friction of the socks and shoes against the skin on the foot while running for an increased period of time. These results coincide with that of Scheer et al. (2011). The total injury/illness rate was 1885.7 per 1 000 runners. These results further correlate with other current literature.
The injuries in this study were reported and recorded within ten minutes of race completion and did not include delayed onset of symptoms (Vernillo et al., 2016). Secondly, participants who retired early from the race were not accounted for, and injury, illnesses or fatigue may have contributed to the non-completion of the race (Vernillo et al., 2016). Consequently, injuries and illnesses may have been unsuccessfully estimated in this study – thereby inadequately reporting on RRIs sustained during the race.

A study by Krabak, Waite, Schiff, (2011), that determined illness and injury rates in multi-day ultramarathon runners recorded data on 396 runners partaking in a multi-day off-road ultramarathon race. The event is predominantly single track routes up the Sierra Nevada mountains of Northern California. Data was documented according to injury severity, type and location. Furthermore, demographics and race information such as age, gender or finishing time was analysed and recorded to determine possible risk factors contributing to injury. The study determined that females had more medical encounters than males and matured runners had 0.5 less injuries. Approximately 95% of the injuries documented were less severe and

included dermatological injuries in the foot (74.3%) (Krabak et al., 2011). This finding correlates to those in studies by Scheer et al., (2011) and Vernillo et al., (2016). They stated that 60% of the medical encounters were medical in nature, rather than MSK and that finishing time was not found to be linked with injury (Krabak et al., 2011).

A study on MSK injuries in mountain races on Spain trail runners participating in 20-42km races found that most injuries occurred in the lower leg (78%), specifically in the ankle (32%), knee (14%) and foot/toe (11%). They described an injury incidence of 1.6 per 1000 hours of running. Furthermore, they reported that 75% of injured runners reported insignificant injuries and were able to complete their races, which coincides with current literature also reporting minor injuries (González-Lázaro et al., 2021). Another study that investigated illness and injury in trail runners competing in an ultra-trail race in the Himalayans found that the most common ailment was acute diarrhoea (18%) followed by MSK problems (17%), abrasions (12%) and blisters (8%). They reported that the most common MSK problem was ankle sprains (Dawadi et al., 2020)

A systematic review (Viljoen et al., 2021c) investigated 11 studies on injury-related matters. They reported that the overall incidence range was 1.6–61.2 injuries per 1000 hours of running. The lower limb is the most frequently injured body region reported, consisting of the lower leg, thigh, knee, foot and ankle (Viljoen et al., 2021c).
Out of these 11 studies, nine reported the foot as a regular anatomical site of injury, trailed by eight studies reporting the knee, seven studies reporting the lower leg, six studies reporting the thigh, and six studies reporting the ankle. Thus, the most common anatomical areas for injury included lower leg, thigh, knee, foot, and ankle. Furthermore, the most common injury diagnoses included skin abrasions/lacerations, skin blisters, ligament sprains, muscle strains, and muscle cramping. Various grades of severity were used to define injury severity: minor severity is indicative that the race/training could be completed, and major severity indicates the cessation of the race/training due to the extent of injury (Viljoen et al., 2021). Interestingly, the systematic review found injuries not reported in road running, such as concussions and contusions and cervical spine strains during race participation. Spinal disc injuries, tibiofibular joint injuries and knee meniscal injuries during training further confirm the difference in demands between road and trail running (Viljoen et al., 2021c).

For this study, it is important to discuss injuries sustained while training towards a specific race, focusing on the two weeks prior to the race. In a population of Portuguese trail runners, 87.8% reported that they sustained an injury from training or competition, with men and women reporting similar outcomes at 88.5% and 85.8%. The injury rate varied from 10.13 per 1000 hours of running in males to 9.62 per 1000 hours of running in females . The anatomical region most affected was the lower limb, with toenails being the most frequent body area (25%), followed by the knee (18%) and ankle (15%). The most common pathology type included blisters (20%), chafing (14%), superficial wounds (12%) and sprains (11%) (Matos et al., 2021). In the four weeks before a multiple distance race in Chile, 31% of trail runners reported having an injury. Thirty percent of the runners that reported an injury reported having one or more injuries in the previous month. Out of these injured runners, 78% had to reduce their training volume, 80% had to change their training intensity, and 85% of runners reported an influence on their performance in the last four weeks, stating that these changes lasted approximately six days. These runners reported that their injuries were gradual onset injuries, most commonly affecting the knee (Gajardo-Burgos et al., 2021b).

When looking specifically at South African trail runners preparing for a specific race, a population of trail runners that trained for the 2019 Sky Run Race, 28% of trail runners mentioned at least one RRI in the 12 months before the race. This equates to a retrospective annual incidence of 49.5 running-related injuries per 1000 hours of running and a point prevalence of 1.3%. These runners reported the most common injured anatomical area as the lower limb (87%) and reported the most frequent body areas as the knee (27%), ankle (22%) and foot (17%). The most common tissue type injury was muscle/tendon (44%), and the most common pathology type included tendinopathy (28%), joint sprains (20%) and muscle injury (16%). Finally, the mean injury severity was 31.6 (Viljoen et al., 2021a). A study on South African trail runners who trained for a 21km or more race distance reported 205 injuries among 152 runners. In this study, 67% of participants developed at least one RRI. They described an injury rate of 15.3 per 1000 hours of running, with males having a significantly higher rate than females (12.7 vs 3.1 per 1000 hours of running). The most frequently reported injured anatomical region was the lower limb (83%), trailed by the hip/groin/pelvis (6%) and the lower back/abdomen (5%). The most common injured body areas were the knee (30%), shin/lower leg (18%) and foot/toe (14%). The most common tissue type was muscle/tendon (53%), and the most common pathology types were tendinopathy (28%), muscle injuries (20%) and joint sprains (9%) (Viljoen et al., 2021b).

From the literature mentioned above, it is important to note that trail runners can experience several RRIs, varying in nature, severity and anatomical site. Furthermore, due to the remoteness of trail running, emergency medical evacuation of injured runners is difficult and therefore, endangered runners will frequently receive impeded medical support. Trail runners are often subjected to punishing environmental factors, and any injury that prevents the runner from moving forward can have fatal consequences in extreme weather conditions. This stresses the need to identify potential injury risk factors to help advance injury prevention strategies among trail runners.

2.9 Trail running injury risk factors

A study by Malliaropoulos et al. (2015) at the National Track and Field Centre in Greece categorised risk factors regarding trail running into three sections: demographic factors, training errors, and medical history. Investigators group risk factors differently. For the purpose of this review, risk factors will be discussed in the following categories: demographics, training variables, running experience and previous injuries (Malliaropoulos et al., 2015).

Demographics

A study by Krabak et al. (2011) stated that female participants competing in a marathon have an increased risk of sustaining hip problems. In contrast, males tend to develop more calf and hamstring problems. This may likely be due to the different Q angle and anatomy of the hip joint in women (Mitani, 2017). Men predominantly experience hamstring shortness, which could justify these findings (Marshall and Siegler, 2014, Krabak et al., 2011). A study by Lorimer, Keogh and Hume (2018) has shown a possible link between lower body stiffness and injury at the Achilles tendinopathy (Lorimer et al., 2018). This could result from muscle imbalances between muscle groups due to fatigue, pain or overuse, resulting in altered recruitment patterns and compensation reactions in the ankle-foot complex. This may lead to unnecessary added load on the tendon and other structures such as the gastrocnemius muscle, tibialis posterior, etc.. Furthermore, one study found that menstrual disturbances in females may result in greater risk of bone stress injuries. The study investigated competitive runners between the ages of 18 and 40 and investigated their training habits, menstrual performance and bone stress injury. They found that bone stress injury were 2.25 times greater in oligo/amenorrhoeic runners than in eumenorrheic runners (Hutson et al., 2021).

Training variables

Different environmental aspects cause ever-changing terrain in trail running (Stasulli, 2015). Lorimer et al. (2018) reported an increased risk for Achilles tendinopathy if a runner changed their training surface from rigid to a softer and less stable surface, in combination with increasing their speed and intensity (Lorimer et al., 2018). This is reinforced by a study led by Nielsen R.O et al. (2014), stating that rapid modifications to training velocity cause injuries. They further stated that faster running speeds are related to Achilles tendinopathy, gastrocnemius injuries, and plantar fasciitis (Nielsen et al., 2014).

In contrast to Lorimer et al. (2018), Malliaropoulos et al. (2015) indicated that training on mountainous trails showed a higher shock absorption when compared to running on asphalt or tartan. They stated that training on rugged terrain provides better defence against the development of RRIs than training on rigid tar roads or tartan tracks. This is due to increased shock absorption created by the ground and the changes in terrain gradients (Malliaropoulos et al., 2015). However, these findings present with inconsistencies across the literature. Trail runners are subjected to increased shock volumes, especially during a downhill trail run, leading to a greater risk of bone-related overuse injuries. The specific foot strike pattern (FSP) influences shock severity and lower-limb movements and may be a potential risk factor for sustaining injuries (Giandolini et al., 2016).

According to a study conducted by (Hoffman and Krishnan, 2014), the annual incidence of stress fractures in ultramarathon runners was reported as 5.5%. They noticed that increased running distance may be a potential risk factor for stress fractures (Hoffman and Krishnan, 2014). They stated that the incidence of osseous injuries can be directly associated to the increased number of heel strikes experienced. During an ultra-trail run of 160 km, a conventional runner would generally encounter 120,000 heel strikes, causing increased stress in the athlete's bones, joints, cartilage and other structures, than a runner participating in a shorter distance (Hoffman and Krishnan, 2014). In contrast, Malliaropoulos et al. (2015) found no correlation among training amount (km/week), exercise sessions/week, double training sessions) and injury prevalence. Nevertheless, they did indicate that trail runners who adhere to a structured training plan, created by a coach, had less injury occurrence than trail runners who trained according to their own experience ($p = 0.0995$).

Running experience

The study by Malliaropoulos et al. (2015) found that experienced runners (>6 years) had an higher prevalence of sustaining an injury ($p=0.001$), predominantly in the tibia ($p=.0.049$),

lower back (p=0.012), and plantar aspect of the foot (p=0.028). These injuries likely resulted due to overuse and training routines. These results are in conjunction with other studies, suggesting that the probability of developing a knee injury is higher amongst experienced runners (Van Middelkoop et al., 2008).

In contrast, another study have found that running experience may be a protective factor. A study by Krabak et al. (2011) reported a diminished risk of total injuries/illnesses, MSK, and skin-related injuries among more experienced runners. Furthermore, veteran runners could focus more on participating and not competing (Krabak et al., 2011).

Medical history

An article by Gaku et al. (2018) reported on possible risk factors responsible for hamstring sprains at high velocity running. The study included 18 non-injured runners and compared them to 18 formerly injured runners. The study identified that formerly injured runners had an increased injury rate compared to the uninjured runners (Gaku et al., 2018). This study's results support those of a study led by Saragiotto et al. (2014), which concluded that the main risk for running-related injuries is previous injuries in the preceding 12 months (Saragiotto et al., 2014).

In conclusion, there are currently 16 studies that have looked at injury risk factors in trail running (Krabak et al., 2011, Costa et al., 2016b, McGowan and Hoffman, 2015, Scheer et al., 2014a, Babí Lladós et al., 2018a, García-Malinis et al., 2021a, Malliaropoulos et al., 2015, Matos et al., 2021, Viljoen et al., 2021d, Viljoen et al., 2021a, Hutson et al., 2021, Hamill et al., 2022a, Armento et al., 2023b, Damoisy et al., 2023a, Matos et al., 2020a, Sanchez-Garcia et al., 2022). In combination these studies found significant injury risk factors to be neglecting warm-up, not following a specialised running protocol, double training sessions per day, constantly training on asphalt, increased running experience >6 years, physical labour occupations, a history of having a RRI (past 12 months), history of allergies, history of chronic diseases, higher weekly running distance, entered for longer race distance, certain trail types and terrains. In addition, a single study found that menstrual dysfunction among females is a risk factor for sustaining bone stress injuries. The studies ruled out risk factors like running distance, running frequency per week, older age, sex and BMI. There is still insufficient consistency in the literature on trail RRIs and associated risk factors.

Only two studies investigated trail RRIs in preparation for a race and on race day in South Africa. A study on 2019 Sky Run race entrants identified no related injury risk factors regarding

training variables or demographics (Viljoen et al., 2021a). However, a study on South African trail runners training for a race distance of 21km or more identified the following risk factors: having a previous running-related injury and a chronic disease. They further found that more biweekly running sessions were associated with a significantly lower risk (Viljoen et al., 2021b). These two studies contradict each other making it difficult to say with certainty if the abovementioned variables are risk factors. This further emphasises the lack of knowledge about trail running injury risk factors in South Africa and the need for more literature on sustaining a RRI. A possible hypothesis may be that the studies had different sample sizes, and thus there may have not been sufficient data on the study investigating the 2019 Sky Run race to find a significant association for injury for the same variables.

According to a narrative review, that reports on injury prevention and safe training techniques, prehabilitation programs may help prevent injuries to progress from acute to overuse injuries. They stated that these programs should include dynamic flexibility, plyometrics as well as neuromotor strength and balance, and that these programs can aid in more stable and controlled movements on trails. Furthermore, they emphasised that patient education on early MSK symptoms as well as training alterations may help prevent injuries to progress to severe overuse injuries. Lastly, step length, modifications to cadence and knee flexion when training on trails may help reduce impact associated risk for injury (Vincent et al., 2022).

It is evident through the literature reviewed above that trail runners present with different injury type profiles and risk factors due to the extreme terrains they are exposed to compared to road runners. This literature review also suggests that the various studies contradict one another. Furthermore, most studies used univariate analysis to determine injury risk factors, which doesn't account for many confounding factors. It is thus important to have more exhaustive research on the possible risk factors associated with trail running.

2.10 Conclusion

In conclusion, it is evident that trail running has increased challenging terrains and extremely demanding conditions compared to road running. Thus, there are increased risks of sustaining RRIs due to these increased demands on the body and alterations in terrain types. Although there is extensive research on the epidemiology of RRIs and related injury risk factors in road running, there is a substantial absence of evidence and consensus on the epidemiology of RRIs and related risk factors amid trail runners. For the provision of successful preventative

strategies for managing and reducing RRIs in trail running, it is important to have an enhanced understanding of trail running-associated injuries and risk factors. This will be obtained by commencing further in-depth research.

Following the literature review, an article as published in the MDPI Journal Applied Sciences, Special issue in Biomechanical Engineering, Advances in Sport Injury Prevention will follow in Chapter 3, followed by a general discussion in Chapter 4.

.

2.11 References

Armento, A. M., Vanbaak, K. D., Seehusen, C. N. & Howell, D. R. 2023. Differences in Training and Health Characteristics Between Trail Ultrarunners and Shorter Distance Runners. *Wilderness & environmental medicine,* 34**,** 182-186.

Babí Lladós, J., Inglés Yuba, E., Cumellas Ruiz, L., Farías Torbidoni, E. I., Seguí Urbaneja, J. & Labrador Roca, V. 2018. Runner's Profile And Propensity To Sports Injury. / El Perfil De Los Corredores Y Su Propensión Al Accidente Deportivo. *International Journal of Medicine & Science of Physical Activity & Sport / Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte,* 18**,** 737-752.

Bakker, E. A., Xuemei, S., Brellenthin, A. G., Duck-Chul, L., Sui, X. & Lee, D.-C. 2018. Physical activity and fitness for the prevention of hypertension. *Current Opinion in Cardiology,* 33**,** 394-401.

Bazgir, B., Salesi, M., Koushki, M. & Amirghofran, Z. 2015. Effects of Eccentric and Concentric Emphasized Resistance Exercise on IL-15 Serum Levels and Its Relation to Inflammatory Markers in Athletes and Non-Athletes. *Asian Journal of Sports Medicine,* 6**,** 1-6.

Butt, M. S., Saleem, J., Zakar, R., Aiman, S., Khan, M. Z. & Fischer, F. 2023. Benefits of physical activity on reproductive health functions among polycystic ovarian syndrome women: a systematic review. *BMC Public Health,* 23**,** 1-9.

Caspersen, C. J., Powell, K. E. & Christenson, G. M. 1985. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public health reports (Washington, D.C. : 1974),* 100**,** 126-131.

Ceyssens, L., Vanelderen, R., Barton, C., Malliaras, P. & Dingenen, B. 2019. Biomechanical Risk Factors Associated with Running-Related Injuries: A Systematic Review. *Sports Medicine,* 49**,** 1095-1115.

Chen, T. C., Nosaka, K. & Wu, C.-C. 2008. Effects of a 30-min running performed daily after downhill running on recovery of muscle function and running economy. *Journal Of Science And Medicine In Sport,* 11**,** 271-279.

Costa, R. J. S., Snipe, R., Camões-Costa, V., Scheer, V. & Murray, A. 2016. The Impact of Gastrointestinal Symptoms and Dermatological Injuries on Nutritional Intake and Hydration Status During Ultramarathon Events. *Sports medicine - open,* 2**,** 16.

Damoisy, J.-B., Destombes, V., Savina, Y., Pröpper, C. J., Braun, C. & Tanné, C. 2023. Epidemiology, prevention methods, and risk factors of foot blisters in French trail ultramarathons. *The Journal of sports medicine and physical fitness,* 63**,** 921-926.

Damsted, C., Nielsen, R. O., Sørensen, H., Glad, S. & Malisoux, L. 2018. Is There Evidence For An Association Between Changes In Training Load And Running-Related Injuries? A Systematic Review. *International Journal of Sports Physical Therapy,* 13**,** 931-942.

Dawadi, S., Basyal, B. & Subedi, Y. 2020. Morbidity Among Athletes Presenting for Medical Care During 3 Iterations of an Ultratrail Race in the Himalayas. *Wilderness & environmental medicine,* 31**,** 437-440.

Dias Lopes, A., Hespanhol Junior, L. C., Yeung, S. S. & Pena Costa, L. O. 2012. What are the Main Running-Related Musculoskeletal Injuries? *Sports Medicine,* 42**,** 891-905.

Dixon, S. J., Collop, A. C. & Batt, M. E. 2000. Surface effects on ground reaction forces and lower extremity kinematics in running. / Les effets du type de sol sur la force de reaction au sol et la cinematique des membres inferieurs dans la course de fond. *Medicine & Science in Sports & Exercise,* 32**,** 1919-1926.

Easthope, C. S., Hausswirth, C., Louis, J., Lepers, R., Vercruyssen, F. & Brisswalter, J. 2010. Effects of a trail running competition on muscular performance and efficiency in well-trained young and master athletes. *European Journal Of Applied Physiology,* 110**,** 1107-1116.

Francis, P., Whatman, C., Sheerin, K., Hume, P. & Johnson, M. I. 2019. The Proportion of Lower Limb Running Injuries by Gender, Anatomical Location and Specific Pathology: A Systematic Review. *Journal of Sports Science & Medicine,* 18**,** 21-31.

Gajardo-Burgos, R., Monrroy-Uarac, M., Barría-Pailaquilén, R. M., Norambuena-Noches, Y., Van Rensburg, D. C. J., Bascour-Sandoval, C. & Besomi, M. 2021. Frequency of Injury and Illness in the Final 4 Weeks before a Trail Running Competition. *International journal of environmental research and public health,* 18.

Gaku, T., Rieko, K., Yuki, M., Shota, E., Yuki, K. & Takuya, S. 2018. The Risk Factors of Hamstring Strain Injury Induced by High-Speed Running. *Journal of Sports Science & Medicine,* 17**,** 650-655.

García-Malinis, A. J., Gracia-Cazaña, T., Zazo, M., Aguilera, J., Rivas-Ruiz, F., De Troya Martín, M. & Gilaberte, Y. 2021. Sun Protection Behaviors and Knowledge in Mountain Marathon Runners and Risk Factors for Sunburn. *Actas dermo-sifiliograficas,* 112**,** 159-166.

Giandolini, M., Horvais, N., Rossi, J., Millet, G. Y., Samozino, P. & Morin, J.-B. 2016. Foot strike pattern differently affects the axial and transverse components of shock acceleration and attenuation in downhill trail running. *Journal of Biomechanics,* 49**,** 1765-1771.

González-Lázaro, J., Arribas-Cubero, H. F. & Rodríguez-Marroyo, J. A. 2021. Muskuloskeletal injuries in mountain running races: A 5 seasons study. *Injury,* 52**,** 747-749.

Hamill, J., Hercksen, J., Salzano, M., Udofa, A. & Trudeau, M. B. 2022. The prevalence of injuries in trail running: influence of trails, terrains and footwear. *Footwear Science,* 14**,** 113-121.

Hoffman, M. D. & Krishnan, E. 2014. Health and exercise-related medical issues among 1,212 ultramarathon runners: baseline findings from the Ultrarunners Longitudinal TRAcking (ULTRA) Study. *PloS one,* 9**,** e83867.

Hollander, K., Johnson, C. D., Outerleys, J. & Davis, I. S. 2021. Multifactorial Determinants of Running Injury Locations in 550 Injured Recreational Runners. *Medicine & Science in Sports & Exercise,* 53**,** 102-107.

Hutson, M. J., O'donnell, E., Petherick, E., Brooke-Wavell, K. & Blagrove, R. C. 2021. Incidence of bone stress injury is greater in competitive female distance runners with menstrual disturbances independent of participation in plyometric training. *Journal of Sports Sciences,* 39**,** 2558-2566.

ITRA (2023) International Trail running Association. Available at: https://itra.run/About/History (Accessed: 28 August 2023).

Jarver, J. & Cheuvront, S. N. 2002. Thermoregulation and marathon running. / Thermoregulation et course de marathon. *Track Coach***,** 5122-5122.

Kakouris, N., Yener, N. & Fong, D. T. P. 2021. A systematic review of running-related musculoskeletal injuries in runners. *Journal of Sport & Health Science,* 10**,** 513-522.

Kemler, E., Blokland, D., Backx, F. & Huisstede, B. 2018. Differences in injury risk and characteristics of injuries between novice and experienced runners over a 4-year period. *The Physician And Sportsmedicine,* 46**,** 485-491.

Krabak, B. J., Waite, B. & Schiff, M. A. 2011. Study of Injury and Illness Rates in Multiday Ultramarathon Runners. *Medicine & Science in Sports & Exercise,* 43**,** 2314-2320.

Le Goff, C., Kaux, J.-F., Laurent, T., Vannuscorps, J., Seidel, L., De La Cruz, C. R., Forthomme, B., Bury, T., Chapelle, J.-P., Cavalier, E. & Croisier, J.-L. 2016. The cardiovascular impact of intense eccentric isokinetic exercise versus aerobic treadmill running. *Isokinetics & Exercise Science,* 24**,** 201-208.

Lee, D.-C., Brellenthin, A. G., Thompson, P. D., Sui, X., Lee, I. M. & Lavie, C. J. 2017. Running as a Key Lifestyle Medicine for Longevity. *Progress in Cardiovascular Diseases,* 60**,** 45-55.

Lee, I. M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., Katzmarzyk, P. T., Lee, I. M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N. & Katzmarzyk, P. T. 2012. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet,* 380**,** 219-229.

Li, C., Ning, G., Xia, Y. & Liu, Q. 2022. Health benefits of physical activity for people with mental disorders: From the perspective of multidimensional subjective wellbeing. *Frontiers in psychiatry,* 13**,** 1050208.

Lorimer, A. V., Keogh, J. W. L. & Hume, P. A. 2018. Using stiffness to assess injury risk: comparison of methods for quantifying stiffness and their reliability in triathletes. *PeerJ,* 6**,** e5845.

Malliaropoulos, N., Mertyri, D. & Tsaklis, P. 2015. Prevalence of Injury in Ultra Trail Running. *Human Movement,* 16**,** 52-59.

Marshall, P. W. M. & Siegler, J. C. 2014. Lower hamstring extensibility in men compared to women is explained by differences in stretch tolerance. *BMC musculoskeletal disorders,* 15**,** 223.

Matos, S., Clemente, F. M., Silva, R. & Cancela Carral, J. M. 2020. Variations of Workload Indices Prior to Injuries: A Study in Trail Runners. *International journal of environmental research and public health,* 17.

Matos, S., Silva, B., Clemente, F. M. & Pereira, J. 2021. Running-related injuries in Portuguese trail runners: a retrospective cohort study. *The Journal of sports medicine and physical fitness,* 61**,** 420-427.

Mcgowan, V. & Hoffman, M. D. 2015. Characterization of medical care at the 161-km Western States Endurance Run. *Wilderness & Environmental Medicine,* 26**,** 29-35.

Mckay, T., Mcewan, L. & Baker, M. 2019. The Rise Of Trail Running In South Africa: Possibilities For Small-Scale Sports Tourism. *GeoJournal of Tourism and Geosites,* 26**,** 930-942.

Mikkelsen, K., Stojanovska, L., Polenakovic, M., Bosevski, M. & Apostolopoulos, V. 2017. Exercise and mental health. *Maturitas,* 106**,** 48-56.

Mitani, Y. 2017. Gender-related differences in lower limb alignment, range of joint motion, and the incidence of sports injuries in Japanese university athletes. *Journal of physical therapy science,* 29**,** 12-15.

Nielsen, R. O., Rønnow, L., Rasmussen, S. & Lind, M. 2014. A Prospective Study on Time to Recovery in 254 Injured Novice Runners. *PLoS ONE,* 9**,** 1-6.

Raghunandan, A., Charnoff, J. N. & Matsuwaka, S. T. 2021. The Epidemiology, Risk Factors, and Nonsurgical Treatment of Injuries Related to Endurance Running. *Current sports medicine reports,* 20**,** 306-311.

Sanchez-Garcia, L. F., Penichet-Tomas, A., Pueo, B. & Jimenez-Olmedo, J. M. 2022. Injury Incidence and Pattern in Elite Young Male and Female Trail Runners. *Applied Sciences,* 12**,** 1155.

Saragiotto, B., Yamato, T., Hespanhol Junior, L., Rainbow, M., Davis, I. & Lopes, A. 2014. What are the Main Risk Factors for Running-Related Injuries? *Sports Medicine,* 44**,** 1153-1163.

Scheer, B. V. & Murray, A. 2011. AI Andalus Ultra Trail: An Observation of Medical Interventions During a 219-km, 5-Day Ultramarathon Stage Race. *Clinical Journal of Sport Medicine,* 21**,** 444-446.

Scheer, B. V., Reljic, D., Murray, A. & Costa, R. J. S. 2014. The enemy of the feet: blisters in ultraendurance runners. *Journal of the American Podiatric Medical Association,* 104**,** 473-478.

Scheer, V., Basset, P., Giovanelli, N., Vernillo, G., Millet, G. P. & Costa, R. J. S. 2020. Defining Off-road Running: A Position Statement from the Ultra Sports Science Foundation. *International Journal of Sports Medicine,* 41**,** 275-284.

Sharif, K., Watad, A., Coplan, L., Lichtbroun, B., Krosser, A., Lichtbroun, M., Bragazzi, N. L., Amital, H., Afek, A. & Shoenfeld, Y. 2018. The role of stress in the mosaic of autoimmunity: An overlooked association. *Autoimmunity reviews,* 17**,** 967-983.

Stasulli, D. (2016) *Comparing the biomechanical demands of different running surfaces*, *Freelap USA*. Available at: https://www.freelapusa.com/comparing-the-biomechanical-demands-of-different-running-surfaces/ (Accessed: 28 August 2023)

Strasser, B., Siebert, U. & Schobersberger, W. 2010. Resistance Training in the Treatment of the Metabolic Syndrome. *Sports Medicine,* 40**,** 397-415.

Van Der Worp, M. P., Ten Haaf, D. S. M., Van Cingel, R., De Wijer, A., Nijhuis-Van Der Sanden, M. W. G. & Staal, J. B. 2015. Injuries in Runners; A Systematic Review on Risk Factors and Sex Differences. *PLoS ONE,* 10**,** 1-18.

Van Middelkoop, M., Kolkman, J., Van Ochten, J., Bierma-Zeinstra, S. M. A. & Koes, B. 2008. Prevalence and incidence of lower extremity injuries in male marathon runners. *Scandinavian Journal of Medicine & Science in Sports,* 18**,** 140-144.

Vannatta, C. N., Heinert, B. L. & Kernozek, T. W. 2020. Biomechanical risk factors for running-related injury differ by sample population: A systematic review and meta-analysis. *Clinical Biomechanics,* 75**,** N.PAG-N.PAG.

Vernillo, C., Savoldelli, A., La Torre, A., Skafidas, S., Bortolan, L. & Schena, F. 2016. Injury and Illness Rates During Ultratrail Running. *International Journal of Sports Medicine,* 37**,** 565-569.

Viljoen, C., Janse Van Rensburg, D. C. C., Van Mechelen, W., Verhagen, E., Silva, B., Scheer, V., Besomi, M., Gajardo-Burgos, R., Matos, S., Schoeman, M., Jansen Van Rensburg, A., Van Dyk, N., Scheepers, S. & Botha, T. 2022. Trail running injury risk factors: a living systematic review. *British journal of sports medicine,* 56**,** 577-587.

Viljoen, C. T., Janse Van Rensburg, D. C., Jansen Van Rensburg, A., Booysen, E., Chauke, S., Coetzee, P., Hurlimann, A., Jooste, M., Nibe, Y., Schulenburg, C., Korkie, E., Ramagole, D., Grant, C. & Cronje, T. 2021a. One in four trail running race entrants sustained an injury in the 12 months training preceding the 2019 SkyRun race. *Physical Therapy in Sport,* 47**,** 120-126.

Viljoen, C. T., Janse Van Rensburg, D. C., Verhagen, E., Van Mechelen, W., Korkie, E. & Botha, T. 2021b. Epidemiology, Clinical Characteristics, and Risk Factors for Running-Related Injuries among South African Trail Runners. *International journal of environmental research and public health,* 18.

Viljoen, C. T., Janse Van Rensburg, D. C., Verhagen, E., Van Mechelen, W., Tomás, R., Schoeman, M., Scheepers, S. & Korkie, E. 2021c. Epidemiology of Injury and Illness Among Trail Runners: A Systematic Review. *Sports medicine (Auckland, N.Z.),* 51**,** 917-943.

Viljoen, C. T., Sewry, N., Schwellnus, M. P., Janse Van Rensburg, D. C., Swanevelder, S. & Jordaan, E. 2021d. Independent Risk Factors Predicting Gradual Onset Injury in 2824 Trail Running Race Entrants: SAFER XVIII Study. *Wilderness & Environmental Medicine,* 32**,** 293-301.

Vincent, H. K., Brownstein, M. & Vincent, K. R. 2022. Injury Prevention, Safe Training Techniques, Rehabilitation, and Return to Sport in Trail Runners. *Arthrosc Sports Med Rehabil,* 4**,** e151-e162.

Wang, Y., Lee, D.-C., Brellenthin, A. G., Eijsvogels, T. M. H., Sui, X., Church, T. S., Lavie, C. J. & Blair, S. N. 2019. Leisure-Time Running Reduces the Risk of Incident Type 2 Diabetes. *American Journal of Medicine,* 132**,** 1225-1232.

Chapter 3

Article as published in the MDPI Journal Applied Sciences, Special issue in Biomechanical Engineering, Advances in Sport Injury Prevention.

Impact factor 2.7.

3. Introduction

Chapter 3 consists of a research article as published in the MDPI open access journal in the format utilised by the specific journal.

Article

One in Five Trail Running Race Entrants Sustained an Injury in the 12 Months Training Period before the 2021 Mac Mac Ultra Race

Mignette Jooste [1,*], Dina C. Janse van Rensburg [2], Volker Scheer [3], Audrey Jansen van Rensburg [2], Dimakatso Ramagole [2], Tanita Botha [4] and Carel Viljoen [1,3]

[1] Department of Physiotherapy, Faculty of Health Sciences, University of Pretoria, Pretoria 0028, South Africa; carel.viljoen@up.ac.za
[2] Section Sports Medicine, Faculty of Health Sciences, University of Pretoria, Pretoria 0028, South Africa; christa.jansevanrensburg@up.ac.za (D.C.J.v.R.); audrey.jansenvanrensburg@up.ac.za (A.J.v.R.); maki.ramagole@up.ac.za (D.R.)
[3] Ultra Sports Science Foundation, 69310 Pierre-Benite, France; volkerscheer@yahoo.com
[4] Department of Statistics, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria 0028, South Africa; u29077096@tuks.co.za
* Correspondence: mignette.vonstaden@gmail.com; Tel.: +27-82-824-7599

Citation: Jooste, M.; Janse van Rensburg, D.C.; Scheer, V.; Jansen van Rensburg, A.; Ramagole, D.; Botha, T.; Viljoen, C. One in Five Trail Running Race Entrants Sustained an Injury in the 12 Months Training Period Before the 2021 Mac Mac Ultra Race. *Appl. Sci.* **2023**, *13*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Received: 21 July 2023
Revised: 18 August 2023
Accepted: 18 August 2023
Published: date

Abstract: Background: Trail running is characterised by large elevation gains/losses and varying uneven running surfaces. Limited literature is available to help guide injury prevention strategies among trail runners. The purpose of this study was to determine the epidemiology, clinical characteristics, and related risk factors for running-related injuries (RRIs) amid trail runners who entered the 2021 Mac Mac Ultra races. Methods: Design: Descriptive cross-sectional study. Setting: 2021 Mac Mac Ultra Race. Participants: Consent for data analysis was given by 251 of 330 (76%) race entrants. Main outcome measures: Point prevalence (%), frequency (n, %), retrospective annual incidence (RRIs/100 athlete-years), characteristics (pathology type, tissue type, body area, anatomical region), and associated injury risk factors (training and demographic variables) of RRIs. Results: In the sample, the retrospective annual incidence was 19.92/100 athlete-years. The point prevalence was 4%. Injuries mostly appeared in the lower limb (95%), with the lower leg (26%), thigh (22%), ankle and foot (13%) described as the highest injured body areas. Of tissue type injuries, muscle/tendon comprised 60%. Muscle injury (36%), tendinopathy (24%), and joint sprain (9%) were the most reported pathology types. No related injury risk factors were discovered in this study. Conclusions: One in five trail runners reported one or more RRI during the 12 months before a competitive event. RRIs commonly involved the lower limb, especially the lower leg, thigh, foot, and ankle. More studies are needed to establish injury risk factors.

Keywords: running-related injuries; clinical characteristics; trail running; epidemiology

1. Introduction

Running is an easily accessible method of physical exertion that has an important role to prevent lifestyle illnesses and early mortality [1]. As a division of off-road running, trail running comprises running outdoors on foot in several types of natural environments (forest, desert, mountain, coastal areas, and jungles/rainforests). Trail running is not restricted by distance or elevation change and takes place over various terrains (e.g., forest trails, single track, dirt road, beach sand, etc.), limiting the amount of paved/asphalt roads to 20–25% of the total race distance [2]. Furthermore, the route is properly marked either by physical markings such as flags, signs, tapes, global positioning system (GPS coordinates), or map indication. Trail run races are usually self-sufficient, with athletes bringing their own equipment, food, and drink. It is important to mention that most ultramarathons (a race distance longer than the standard marathon distance of 42.195 km) held off-road can be considered as trail running [2]. Trail runners are typically exposed to large elevation changes due to running in natural environments such as mountains. Although running presents with numerous health benefits, there is still a high risk of injury in trail running [3].

A living systematic review showed an injury incidence range of 0.7–61.2 injuries/1000 h of running among 12 studies that reported injury incidence in trail running [4-14]. Nineteen studies in current literature reported injury prevalence in trail running, ranging between 1 and 90% [5,6,8-12,15-26]. The body region most commonly injured in all studies reviewed is the foot/toe, ankle, and hip. The most common injury diagnosis reported was superficial tissue/skin injuries, muscle/tendon injuries, and ligament/joint capsule injuries [27]. They reported that the ankle was more frequently injured than the knee, specifically acute ankle sprains [3,8]. Furthermore, more severe injuries identified in this review included bone fractures, as well as concussions [9,10,28].

In trail running, multiple extrinsic and intrinsic injury risk factors are reported to have a significant association with injury among trail runners [27]. Identified risk factors include neglecting a warmup, not using a specialised training plan, training on asphalt, more than one training session a day, increased weekly running distance, longer race distance entered, and different race terrains [9,12,26]. Furthermore, running experience of more than six years, jobs with physical labour, a history of a running-related injury, and a history of allergy or chronic illness were also identified as risk factors [11,26]. Interestingly, specific to women, a link to menstrual dysfunction and bone stress fractures was identified [13]. These studies reported on individual risk factors related to the context of that specific study, while limited studies found associations with similar factors across various trail running settings [27]. Certain trail running races, such as the Mac Mac Ultra race in South Africa, are held in inaccessible locations where medical support is difficult and limited [29]. Trail runners who sustain an injury which results in an inability to proceed with running incur the risk of exposure to life-threatening conditions and extreme weather conditions while awaiting medical support [29]. It is therefore necessary to better understand the injury prevalence and injury profiles of injured runners who will start an ultra-trail running race, as the exacerbation of injury in an ultra-trail race might prove detrimental. Better knowledge could help race medical organisers plan more efficiently in terms of preparedness, management, and evacuation of runners on race-day. Understanding

which factors are associated with injury during the training months before a race is important. This will help clinicians and runners mitigate the risk of injury in the training period ahead of the race.

We hypothesised that factors in the domains of runner demographics, training characteristics, and race distance entered would be associated with different levels of risk for injury. The objective of the study was to examine the epidemiology, as well as clinical characteristics of RRIs between race entrants of the 2021 Mac Mac Ultra race during the 12 months before the event and specifically the two weeks before the race. We further aimed to define associated risk factors in this trail running population.

2. Materials and Methods

2.1. Study Design

A retrospective cross-sectional study design was used in this study, examining data assembled two weeks before the 2021 Mac Mac Ultra Race, South Africa.

2.2. Participants and Data Collection

The study population was trail runners who entered any race distance category at the 2021 Mac Mac Ultra race (46 km, 80 km, 161 km, or 322 km), hosted in a mountainous region of the Mpumalanga province, South Africa. All the athletes completed an obligatory online pre-race medical screening questionnaire two weeks before the event. Two weeks before the race, race organisers shared the online questionnaire link in the pre-race information pack that each race entrant received via email. The online pre-race medical screening questionnaire (online Supplementary Materials) was hosted on the Qualtrics™ platform. The day before the race, each runner had to report to the race venue to allow for a compulsory race gear check procedure. There, the medical staff ensured that all runners completed the online pre-race medical questionnaire. For the purpose of our research, we only analysed the data of race entrants that provided informed consent after the completion of the medical screening process, were 18 years or older, and entered one of the races at the 2021 Mac Mac Ultra event. Since the study population was well-defined, consisted of small numbers, and the whole population could be accessed, we utilised total population sampling in this study aiming to include 100% of the study population (Figure 1).

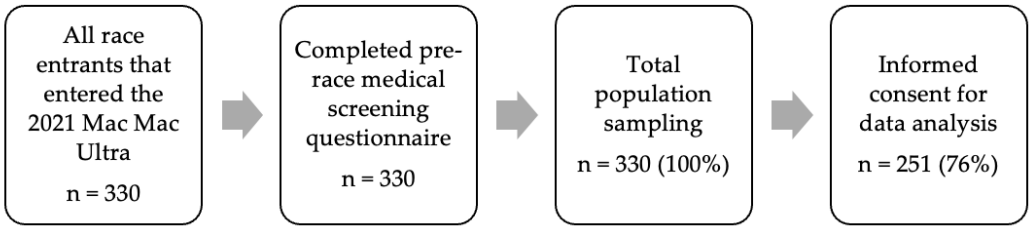


Figure 1. Flow chart of total population sampling.

Data gathered during the pre-race medical screening process included trail runners' demographics (BMI, height, age, running experience, weight), training variables with respect to running (weekly frequency, weekly distance, surface, average pace, shoes, vertical gain,

cross-training), injury history (clinical characteristics of injury, RRI in the past 12 months, current RRI, severity of injury), history of disease (chronic disease, current illness), and usage of medication (current, chronic medication). The questionnaire is used in pre-race medical screening at various trail running events across South Africa [10]. Race entrants self-report their injuries sustained in the past 12 months by responding "yes" to the question: "Did you sustain **any running-related injuries** in the past 12 months?". Runners currently injured had selected "injury" in response to the question: Do you have a current injury or illness? If "injury" was selected, then additional questions were posed in relation to the four main considerations of the Oslo Sports Trauma Research Center Questionnaire on Health Problems (OSTRC-H) [30]. To be recorded as a current injury, the race entrant had to indicate that training modification was needed during the two weeks before the race. Furthermore, similar to the study on the 2019 Sky Run Race, questions that focused on the clinical aspects of injuries were asked [10]. After data collection, the data were coded and stored in an Excel spreadsheet keeping entrants' information anonymous. The data will be stored for a minimum of 10 years at the Department of Physiotherapy, University of Pretoria. For this study, only the injury-related data were analysed.

2.3. Ethical Considerations

This study forms part of a bigger project: "Reducing Injuries and Illness at Adventure Sports Events: A 10-Year Longitudinal Study (2018–2028)" (REC: 460/2018) that the Research Ethics Committee (REC) of the University of Pretoria approved. Before conducting this sub-study, another protocol was submitted to the REC to provide a detailed description of the framework underlying the data analysis in this study. Following the review process, the REC at the University of Pretoria also approved this study (REC: 404/2022). The pre-race medical screening process was designed to provide at-risk race entrants with additional medical information to benefit them in safer race participation. None of the participants were exposed to any physical or mental harm during this study. All participants were provided with the study information and were required to give informed consent to analyse their pre-race medical screening data. The study information document contained the research team's contact details, allowing participants to ask any additional questions regarding the study. No deception or coercion was involved in the recruitment of participants. Participants could decline the opportunity to participate or withdraw from the study at any time and not be negatively affected by this decision in any way. Participants' data were treated confidentially. De-identified data were provided to the research team by the custodian of the pre-race medical screening data. Furthermore, our data analysis and reporting ensured no identification of a participant through the data presented in the results section of this publication.

2.4. Study Outcomes

We reported the point prevalence (% of current participants who were injured), retrospective annual incidence (RRIs per 100 athlete-years), and frequency (n,%) of RRI clinical characteristics (pathology type, tissue type, body area, anatomical region) in agreement with the 2020 International Olympic Committee (IOC) consensus statement for reporting and recording of epidemiological data on sports injuries [31].

Race entrants could report up to three injuries for a section related to being currently injured. The variables of BMI, sex, age, average weekly vertical gain, average weekly running distance, total years of active trail running, total years of active running, the average number of trail running sessions per week, and average number of any running sessions per week were investigated as possible related injury risk factors (OR, *p*-values).

2.5. Statistical Analysis

We used the Pearson Chi square test to compare categorical variables of all athletes in the event versus consenting athletes in the event to establish if our sample was demonstrative of the population (all 2021 Mac Mac Ultra race entrants). Frequencies (%) of injury for pathology type, tissue type, body area, and anatomical region utilised descriptive statistics. Inferential statistics (Independent *t*-test and Mann Whitney U test, and Chi Squared tests) were applied to contrast the training and demographic data of entrants between injured and non-injured entrants to examine and find connected injury risk factors. Odds ratios were calculated using binary logistic regression to investigate further the association between exposure and outcome (sustaining RRIs). Entrants were categorised into those who experienced an RRI during the previous 12 months vs. non-injured participants. Due to zero of the univariate examinations yielding statistically significant results ($p < 0.05$), a multivariate evaluation was omitted.

3. Results

3.1. Demographics of Race Entrants

A total of 330 trail running athletes entered the 2021 Mac Mac Ultra race, and 251 (76%) race entrants gave consent for the use of their data in this study (46 km (n = 156), 80 km (n = 58), 161 km (n = 28), 322 km (n = 9)). Table 1 confirms that no statistically significant difference existed between all race entrants (population) and consenting race entrants (our sample) and race distances ($p = 0.423$) and in the sex ($p = 0.701$), which indicates a representative study sample. Most consenting race entrants were males (70%, n = 232), while most of the participants entered the 46 km race category (56%, n = 185).

Table 1. Characteristics (sex, race distance) of all athletes and consenting athletes.

Characteristics		All Trail Run Entrants (n = 330)		Trail Runners Consenting as Study Participants (n = 251)		*p*-Value
		n	% of All Entrants	n	% of Study Participants	
Sex	Males	232	70	181	72	0.701
	Females	98	30	70	28	
Race Distance	46 km	185	56	156	62	0.423
	80 km	85	26	58	23	
	161 km	49	15	28	11	
	322 km	11	3	9	4	

As noted in Table 2, the 161 km race entrants had the peak mean age (44 years), height (181 cm), and weight (76 kg). The 161 km race entrants also had the lowest mean BMI (23 kg/m^2). Males reported a higher height (180 cm), age (40 years), weight (78 kg), and BMI (24 kg/m^2) compared to female race entrants.

Table 2. Characteristics of mean age (years), height (cm), weight (kg), and BMI (kg/m^2) by distance categories (46 km, 80 km, 161 km, 322 km).

Characteristic of Participants		All Consenting Race Entrants (n = 251)	46 km (n = 156)	80 km (n = 58)	161 km (n = 289)	322 km (n = 9)
Mean age (years) Missing (n = 0)	All participants	40	39	39	44	43
	Males	40	40	39	44	43
	Females	40	39	41	46	42
Mean height (cm) Missing (n = 0)	All participants	176	176	175	181	177
	Males	180	180	178	183	180
	Females	167	168	166	170	148
Mean weight (kg) Missing (n = 4)	All participants	73	73	72	76	74
	Males	78	78	76	78	77
	Females	61	62	59	60	52
Mean BMI (kg/m^2) Missing (n = 4)	All participants	23	24	24	23	24
	Males	24	24	24	23	24
	Females	22	22	21	21	24

BMI: Body Mass Index.

3.2. Running surface exposure

Across all race distances, the preferred training surface among race entrants included dirt roads (trails) (n = 193; 77%) followed by road/street (n = 186; 74%). Race entrants rarely trained on treadmills (n = 19; 8%) or tartan (track) (n = 4; 2%) (Figure 2).

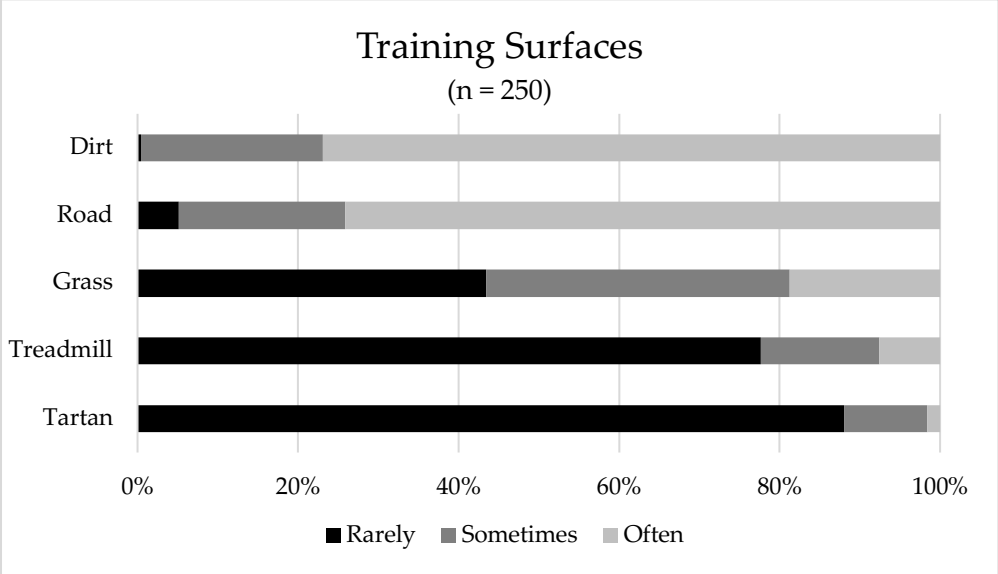


Figure 2. The frequency (n, %) of reported running surfaces trained on often, sometimes, and rarely by consenting race entrants.

3.3. Epidemiology (Point Prevalence and Retrospective Annual Incidence) of RRIs among Consenting Race Entrants

The retrospective annual incidence of RRIs for trail runners that developed an injury in the last 12 months was 19.92 per 100 athlete-years. Amongst the 251 consenting trail runners, 50 (20%) reported an RRI in the 12 months before the race, and 20 (40%) of these runners still experienced symptoms at the start of the race. The point prevalence of injury reported in the two weeks before the race was 4%.

3.4. Clinical Characteristics of RRIs among the Consenting Race Entrants in the Past 12 Months

The clinical characteristics of RRIs are offered in the groups of injured anatomical region, body area, tissue type, and pathology type.

Table 3 depicts the frequencies (%) and number (n) of RRIs (anatomical region, body area) in the past 12 months and two weeks before the race through all race distance classes.

Table 3. RRIs amid consenting race entrants by anatomical region and specific body area (% RRIs) (n = 55; n = 12).

Anatomical Region	Body Area	Injuries Reported in the 12 Months Leading Up to the Race		Injuries Reported in the Two Weeks before the Race	
		Number of RRIs (n = 55)	% of All RRIs	Number of RRIs (n = 12)	% of All RRIs
Upper Limb	All	-	-	1	8
	Hand	-	-	1	8
Trunk	All	2	4	1	8
	Lumbosacral	2	4	1	8
Lower Limb	All	52	95	10	83
	Hip/groin	2	4	2	17
	Thigh	12	22	-	-
	Knee	5	9	2	17
	Lower leg	14	26	2	17
	Ankle	7	13	1	8
	Foot	7	13	3	25
Unspecified		6	11	-	-

The anatomical region most affected by RRIs in the 12 months leading up to the race and in the two weeks before the race was the lower limb (12 months: 95%, n = 52; 2 weeks: 83%, n = 10). The main body areas injured in the 12 months leading up to the race were the lower leg (26%, n = 14), followed by the thigh (22%, n = 12), and both ankle and foot (13%, n = 7). The most injured body areas reported two weeks before the race were the hip/groin, knee, and lower leg (17%, n = 2).

Table 4 portrays the frequencies (%) and number (n) of RRIs (pathology and tissue type) in the past 12 months and two weeks before the race across all four race distance categories.

Table 4. RRIs among consenting race entrants by tissue and pathology type (% RRIs) (n = 55).

Tissue Type	Pathology Type	Injuries Reported in the 12 Months Leading Up to the Race		Injuries Reported in the Two Weeks before the Race	
		Number of RRIs (n = 55)	% of All RRIs	Number of RRIs (n = 12)	% of All RRIs
Muscle/Tendon	All	33	60	7	58
	Muscle injury	20	36	3	25
	Tendinopathy	13	24	4	33
Nervous	All	1	2	1	8
	Peripheral nerve injury	1	2	1	8
Bone	All	3	5	1	8
	Fracture	2	4	-	-
	Bone contusion	1	2	-	-
Cartilage/Synovium/Bursa	All	2	4	1	8
	Cartilage injury	1	2	-	-
	Bursitis	1	2	1	8
Ligament/Joint capsule	All	5	9	2	17
	Joint sprain	5	9	2	17
Nonspecific	All	11	20	1	8

Muscle and tendon type injuries represent the majority of RRIs among race entrants for both injuries sustained in the 12 months before the race and in the two weeks before the race (12 months: 60%, n = 33; 2 weeks: 58%, n = 7). Muscle injury (12 months: 36%, n = 20; 2 weeks: 25%, n = 7), tendinopathy (12 months: 24%, n = 13; 2 weeks: 33%, n = 4), and

joint sprain (12 months: 9%, n = 5; 2 weeks: 17%, n = 2) were the pathology types most affected by RRIs in both the 12 months and two weeks before the race.

3.5. Univariate Analysis (Unadjusted) of Potential Risk Factors Associated with RRIs among Consenting Race Entrants in the 12 Months before the Race

The following variables were investigated as related RRI risk factors amongst consenting race entrants: BMI, sex, age, average weekly vertical gain, average weekly running distance, total years of active trail running, total years of active running, the average number of weekly trail running sessions, and average number of weekly running sessions.

Table 5 represents the univariate examination results (*p*-values) with the statistical significance set at $p < 0.05$.

Table 5. Univariate analysis (Odds ratio, 95% CI, *p*-value) of variables in relation to RRIs sustained in 12 months preceding the race.

Variable		OR (95% CI)	*p*-Value
Age		1.01 (0.97–1.05)	0.709
Sex		0.59 (0.26–1.21)	0.168
BMI		0.96 (0.85–1.07)	0.433
46 km		1.94 (0.81–4.43)	0.123
80 km		1.06 (0.41–2.68)	0.900
Average weekly vertical gain	501–1000 m	1.01 (0.44–2.28)	0.974
	1001–1500 m	0.93 (0.37–2.36)	0.880
	>1501 m	1.08 (0.42–2.91)	0.871
Total running experience >5 years	Running	1.39 (0.71–2.64)	0.326
	Trail running	1.62 (0.85–3.19)	0.149
Average number of running sessions per week >3 sessions	Running sessions	1.93 (0.90–3.98)	0.082
	Running sessions on trail	1.16 (0.50–3.03)	0.738

CI: Confidence Interval. OR: Odds ratio.

None of the variables listed in Table 5 showed a statistically significant connotation with sustaining RRIs in the 12 months before the race.

4. Discussion

This study investigates trail runners competing in the 2021 Mac Mac Ultra Race. Our key findings are: (1) 20% of participants described one or more RRI in the 12 months before the race, portraying a retrospective annual incidence of 19.92 per 100 athlete-years and a point-prevalence of 4%; (2) most injuries involved in the lower limb in the 12 months (95%) and two weeks (83%) before the race; (3) the body areas most commonly injured in the 12 months before the race was the lower leg (26%), thigh (22%), ankle (13%), and foot (13%). In the two weeks before the race, the most commonly injured body areas were the foot (25%), hip/groin (17%), knee (17%), and lower leg (17%); (4) in both the 12 months (60%) and two weeks (58%) before the race, the tissue type muscle/tendon was the most common injury; (5) muscle injury (36%), tendinopathy (24%), and joint sprain (9%) were the most frequent pathology types reported in the 12 months before the race. However, during the two weeks before the race, tendinopathy (33%), muscle injury (25%), and joint sprain (17%) were reported; (6) no variables involved in the univariate investigation showed a significant connotation with RRIs.

According to the living systematic review, 14 studies investigated training/race-related injury outcomes [27]. In these studies, runners were exposed to diverse running surfaces and ecological settings, making it challenging to compare our results with the current literature.

Furthermore, only four of these studies investigated the same variables for comparison to our results.

4.1. Epidemiology of Injury

According to a cross-sectional study examining 40 Greek trail runners, at least one RRI was reported by 90% of the sample [26]. Of 719 trail runners in a retrospective cross-sectional study in Portugal, 87.7% reported a RRI during training [9]. Moreover, 42.1% of Dutch trail runners reported a RRI during the previous 12 months of training, with 18% stating being currently injured with an incidence of 10.7 injuries per 1000 h of running [8]. The abovementioned studies have a much bigger percentage of injury compared to our study, where only 20% of trail runners reported a RRI during the last 12 months. Furthermore, a study of Spain trail runners competing in mountain races recorded an injury incidence of 1.6 per 1000 h of running with 75% of participants reporting a minor musculoskeletal injury [7]. Another study on trail runners competing in the Himalayas reported an incidence of 30.7 per 1000 h of running [6]. These differences in the percentage of injuries during training might be due to different landscapes in the different countries where trail runners train.

Similar to our study, a retrospective cross-sectional study on South African trail runners reported that 28% of runners had at least one RRI in the 12 months prior the race [10]. In the current study, only 1% of runners reported injury at the day of the race, and 4% of runners reported injuries in the two weeks before the race. This low prevalence is in keeping with the retrospective cross-sectional study and can be due to false reporting because runners fear disqualification before the start of the race.

4.2. Clinical Characteristics of Injury

4.2.1. Anatomical Region and Body Area

Similar to the findings of the living systematic review, the lower limb was the most frequent anatomical region of injury in our study in both the 12 months (95%) and the two weeks before the race (83%). The study on Spain trail runners in the Al Andalus Ultra trail reported the lower limb as the most common anatomical region for injury (22%) with the knee being the most common (17%) [14]. The study on Greek trail runners reported the lower leg as the most frequent anatomical region (20%), followed by the knee (18%) and foot (15%). These trail runners reported the lower back (43%) as the most commonly reported injured body area, followed by the knee (40%) [26]. Although our study also reported the lower leg (26%) and foot (13%) as commonly injured, unlike the two above mentioned studies [8,26], the knee was not reported as a frequent anatomical region of injury. The difference could be that in Greece, training is mostly on mountainous terrain, according to the study. In contrast, most of our participants trained five or more sessions per week on road surfaces (50%) and less than 1000 m elevation gain per week (50%). Another study on South African trail runners described the most common body area injured as the knee (27%), followed by the ankle (22%) and foot (17%) [10]. Our most reported body area was the lower leg (26%). A study on trail runners in Spain reported the lower limb as the most injured anatomical region (78%), and the most injured body area was the ankle (32%), followed by the knee (14%) and foot/toe (11%). They did however report injuries in the upper limb (18%) where the trunk was the

most common (7%) [7]. The difference between the studies may be because the participants of these studies trained for different races in different geographical settings regarding terrain and elevation changes. Participants also trained for different race distances.

In our study, in the two weeks before the race, the foot (25%) was the most reported injured body area, followed by the hip/groin (17%), knee (17%), and lower leg (17%). Our study is the first to investigate injuries in the two weeks before the race and thus cannot be compared to other studies.

4.2.2. Tissue and Pathology Type

In our study, the muscle/tendon was the most injured tissue type reported among all consenting trail runners in the 12 months (60%) and two weeks (58%) before the race. This coincides with the Dutch (28%) and South African (44%) trail runners [8,10].

The most frequent pathology type reported was muscle injuries (36%) among all trail runners in our study, followed by tendinopathy (24%) and joint sprains (9%). This agrees with the results of the Dutch study that stated muscle injuries (28%) as the most frequently injured tissue type, followed by tendon injuries (24%) and ligament injuries (7%) [8]. The study on Greek trail runners found overuse bone injuries to be the most common tissue and pathology type (22%) followed by iliotibial band syndrome (ITBS) (16%) and meniscus and spinal disk injuries (14%) [26] Our results are further supported by the retrospective cross-sectional study on South African trail runners that reported tendon injuries (28%) as the most common injured tissue type, followed by joint sprains (20%) and muscle injuries (16%) [10]. According to the study on trail runners in the Al Andalus Ultra Trail in Spain, patellofemoral pain syndrome was the most common pathology type (7%), followed by Achilles tendinopathy (3%) and ultramarathoner's ankle, which classifies as tendinopathy (1%) [14]. This also coincides with our results from the two weeks before the race: tendinopathy (33%), muscle injury (25%), and joint sprain (17%). This is important to note as running demands repetitive lower limb movements where soft tissue is required to absorb ground reaction forces [32]. Furthermore, trail running requires increased eccentric muscle control, especially during steep descents, which can result in added muscle damage. This unique pattern of recurring ground force absorption and increased eccentric control could cause the increased occurrence of tendon and muscle injuries described among trail runners [33].

Interestingly, only 9% of injuries were reported as joint sprains. This difference from the 20% in the retrospective cross-sectional study might be due to our participants training for a different geographical area, race distance, and elevation gain [10]. Our injury data from the two weeks before the race, however, showed a similar result as the retrospective cross-sectional study for joint sprains (17%); this might be because nearing the race date, runners trained more on trails in preparation for the race [10].

4.2.3. Associated Injury Risk Factors

In total, 16 studies [4,9,10,12,13,15,16,18-20,22-24,26,34] reported injury risk factors in trail running literature to date. Among Greek trail runners, physical labour, double training sessions, and more than six years of running experience were risk factors for injury. The study on trail

runners in Portugal found no warm up and less exposure time as risk factors for sustaining injuries [9,26]. In contrast to the abovementioned studies, none of the variables involved in the univariate investigation in our study showed a statistically significant connotation with developing an RRI in the 12 months before the 2021 Mac Mac Ultra. Therefore, we could not reject our null hypothesis, i.e., we found no association between injury and demographics, training characteristics, or race distance entered. This is similar to the retrospective cross-sectional study on South African trail runners [10]. These inconsistent findings indicate the complex nature of sports injuries [35]. Sports injuries do not occur in isolation but are likely due to multifaceted relationships between various variables, known as a "web of determinants" [35]. This study examined a limited number of possible injury risk factors as per the sample size and information available. Further studies utilising greater sample sizes should incorporate more intrinsic variables and have a multivariate examination to assess potential injury risk factors.

4.3. Strengths and Limitations

A strength of this study was that 76% of all the 2021 Mac Mac Ultra race entrants consented to participate in the study and were a confirmed illustrative sample of the total population. This study addresses the significant lack of trail running information concerning the clinical characteristics and epidemiology of injury in preparation for trail run races. The results of this study need to be considered in the context of the limits such as recall bias of the cross-sectional study that used self-reported injury statistics based on injuries that transpired during the previous 12 months. The low point prevalence might be due to trail runners dreading disqualification due to the pre-race medical screening procedure. Upcoming studies should aim for prospective cohort study designs with frequent follow-up to limit recall bias. We acknowledged that participants might have misunderstood all the medical terms used to report injury pathology in this questionnaire. The lack of identified injury risk factors may be due to the small sample size. We acknowledge that runners with severe injuries that were unable to participate would not have been at race registration to fill out the questionnaire; thus, those injuries would not have been included in the study. Furthermore, we acknowledge that we studied a particular population of trail runners preparing for a specific race in a rugged region at extreme altitudes. Hence, the results of this study cannot be universalised to trail runners preparing towards races in diverse environmental settings (desert, forest etc.).

5. Conclusions

One in every five Mac Mac Ultra trail runners reported one or more injuries in the previous 12 months. Trail runners preparing for the 2021 Mac Mac Ultra race reported RRIs most commonly affecting the lower limb, explicitly the lower leg, thigh, ankle, and foot. Furthermore, our study identified that runners may choose to compete regardless of an injury. This accentuates the necessity to identify injury risk factors to aid in designing injury prevention tactics, since the occurrence of injury during a trail run may have devastating complications.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, File S1: Mac Mac Ultra Pre-race 2021.

Author Contributions: Conceptualisation, C.V. and D.C.J.v.R.; methodology, M.J., C.V., V.S., and D.C.J.v.R.; formal analysis, T.B., M.J., and C.V.; data collection, M.J., C.V., D.C.J.v.R., D.R., A.J.v.R., and T.B.; data curation, C.V.; writing—original, M.J.; writing—review and editing, M.J., C.V., D.C.J.v.R., D.R., V.S., A.J.v.R., and T.B..; visualisation, M.J., C.V. and D.C.J.v.R; supervision, C.V. and D.C.J.v.R.; project administration, C.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of University of Pretoria (protocol code REC: 404/2022) approved on 13 July 2022.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Strasser, B.; Siebert, U.; Schobersberger, W. Effects of resistance training on respiratory function in patients with chronic obstructive pulmonary disease: a systematic review and meta-analysis. *Sleep & Breathing = Schlaf & Atmung* **2013**, *17*, 217-226, doi:10.1007/s11325-012-0676-4.

2. Scheer, V.; Basset, P.; Giovanelli, N.; Vernillo, G.; Millet, G.P.; Costa, R.J.S. Defining Off-road Running: A Position Statement from the Ultra Sports Science Foundation. *International Journal of Sports Medicine* **2020**, *41*, 275-284.

3. Vernillo, C.; Savoldelli, A.; La Torre, A.; Skafidas, S.; Bortolan, L.; Schena, F. Injury and Illness Rates During Ultratrail Running. *International Journal of Sports Medicine* **2016**, *37*, 565-569.

4. Krabak, B.J.; Waite, B.; Schiff, M.A. Study of injury and illness rates in multiday ultramarathon runners. *Med Sci Sports Exerc* **2011**, *43*, 2314-2320, doi:10.1249/MSS.0b013e318221bfe3.

5. Sanchez-Garcia, L.F.; Penichet-Tomas, A.; Pueo, B.; Jimenez-Olmedo, J.M. Injury Incidence and Pattern in Elite Young Male and Female Trail Runners. *Applied Sciences* **2022**, *12*, 1155.

6. Dawadi, S.; Basyal, B.; Subedi, Y. Morbidity Among Athletes Presenting for Medical Care During 3 Iterations of an Ultratrail Race in the Himalayas. *Wilderness & environmental medicine* **2020**, *31*, 437-440, doi:10.1016/j.wem.2020.08.001.

7. González-Lázaro, J.; Arribas-Cubero, H.F.; Rodríguez-Marroyo, J.A. Muskuloskeletal injuries in mountain running races: A 5 seasons study. *Injury* **2021**, *52*, 747-749, doi:10.1016/j.injury.2020.10.045.

8. Hespanhol Junior, L.; van Mechelen, W.; Verhagen, E. Health and Economic Burden of Running-Related Injuries in Dutch Trailrunners: A Prospective Cohort Study. *Sports Medicine* **2017**, *47*, 367-377, doi:10.1007/s40279-016-0551-8.

9. Matos, S.; Silva, B.; Clemente, F.M.; Pereira, J. Running-related injuries in Portuguese trail runners: a retrospective cohort study. *The Journal of sports medicine and physical fitness* **2021**, *61*, 420-427, doi:10.23736/S0022-4707.20.11304-5.

10. Viljoen, C.T.; Janse van Rensburg, D.C.; Jansen van Rensburg, A.; Booysen, E.; Chauke, S.; Coetzee, P.; Hurlimann, A.; Jooste, M.; Nibe, Y.; Schulenburg, C.; et al. One in four trail running race entrants sustained an injury in the 12 months training preceding the 2019 SkyRun race. *Physical Therapy in Sport* **2021**, *47*, 120-126, doi:10.1016/j.ptsp.2020.11.029.

11. Viljoen, C.T.; Janse van Rensburg, D.C.; Verhagen, E.; van Mechelen, W.; Korkie, E.; Botha, T. Epidemiology, Clinical Characteristics, and Risk Factors for Running-Related Injuries among South

African Trail Runners. *International journal of environmental research and public health* **2021**, *18*, doi:10.3390/ijerph182312620.

12. Viljoen, C.T.; Sewry, N.; Schwellnus, M.P.; Janse van Rensburg, D.C.; Swanevelder, S.; Jordaan, E. Independent Risk Factors Predicting Gradual Onset Injury in 2824 Trail Running Race Entrants: SAFER XVIII Study. *Wilderness & Environmental Medicine* **2021**, *32*, 293-301, doi:10.1016/j.wem.2021.04.002.

13. Hutson, M.J.; O'Donnell, E.; Petherick, E.; Brooke-Wavell, K.; Blagrove, R.C. Incidence of bone stress injury is greater in competitive female distance runners with menstrual disturbances independent of participation in plyometric training. *Journal of Sports Sciences* **2021**, *39*, 2558-2566.

14. Scheer, B.V.; Murray, A. AI Andalus Ultra Trail: An Observation of Medical Interventions During a 219-km, 5-Day Ultramarathon Stage Race. *Clinical Journal of Sport Medicine* **2011**, *21*, 444-446.

15. Costa, R.; Snipe, R.; Camões-Costa, V.; Scheer, V.; Murray, A. The Impact of Gastrointestinal Symptoms and Dermatological Injuries on Nutritional Intake and Hydration Status During Ultramarathon Events. *Sports Med Open* **2016**, *2*, 1-14.

16. García-Malinis, A.J.; Gracia-Cazaña, T.; Zazo, M.; Aguilera, J.; Rivas-Ruiz, F.; de Troya Martín, M.; Gilaberte, Y. Sun Protection Behaviors and Knowledge in Mountain Marathon Runners and Risk Factors for Sunburn. *Actas Dermosifiliogr* **2021**, *112*, 159-166, doi:10.1016/j.ad.2020.11.003.

17. Graham, S.M.; Martindale, R.J.J.; McKinley, M.; Connaboy, C.; Andronikos, G.; Susmarski, A. The examination of mental toughness, sleep, mood and injury rates in an Arctic ultra-marathon. *Eur J Sport Sci* **2021**, *21*, 100-106, doi:10.1080/17461391.2020.1733670.

18. Hoffman, M.D.; Stuempfle, K.J. Muscle Cramping During a 161-km Ultramarathon: Comparison of Characteristics of Those With and Without Cramping. *Sports Med Open* **2015**, *1*, 24-24.

19. Matos, S.; Clemente, F.M.; Silva, R.; Cancela Carral, J.M. Variations of Workload Indices Prior to Injuries: A Study in Trail Runners. *Int J Environ Res Public Health* **2020**, *17*, doi:https://dx.doi.org/10.3390/ijerph17114037.

20. Scheer, B.V.; Reljic, D.; Murray, A.; Costa, R.J.S. The enemy of the feet: blisters in ultraendurance runners. *J Am Podiatr Med Assoc* **2014**, *104*, 473-478, doi:https://dx.doi.org/10.7547/0003-0538-104.5.473.

21. Gajardo-Burgos, R.; Monrroy-Uarac, M.; Barría-Pailaquilén, R.M.; Norambuena-Noches, Y.; van Rensburg, D.C.J.; Bascour-Sandoval, C.; Besomi, M. Frequency of Injury and Illness in the Final 4 Weeks before a Trail Running Competition. *Int J Environ Res Public Health* **2021**, *18*, doi:10.3390/ijerph18105431.

22. Hamill, J.; Hercksen, J.; Salzano, M.; Udofa, A.; Trudeau, M.B. The prevalence of injuries in trail running: influence of trails, terrains and footwear. *Footwear Science* **2022**, 1-9.

23. Armento, A.M.; VanBaak, K.D.; Seehusen, C.N.; Howell, D.R. Differences in Training and Health Characteristics Between Trail Ultrarunners and Shorter Distance Runners. *Wilderness Environ Med* **2023**, *34*, 182-186, doi:10.1016/j.wem.2022.12.002.

24. Damoisy, J.-B.; Destombes, V.; Savina, Y.; Pröpper, C.J.; Braun, C.; Tanné, C. Epidemiology, prevention methods, and risk factors of foot blisters in French trail ultramarathons. *The Journal of Sports Medicine and Physical Fitness* **2023**.

25. Zapata-Rodrigo, R.; Ramírez Parenteau, C.; Escribano-Rodríguez, M.; Vicente-Romero, J. Musculoeskeletal injuries and illnesses in the Spanish team the month prior to the WMTRC 2022. *Apunts Sports Medicine* **2023**, *58*, 100405, doi:https://doi.org/10.1016/j.apunsm.2023.100405.

26. Malliaropoulos, N.; Mertyri, D.; Tsaklis, P. Prevalence of Injury in Ultra Trail Running. *Human Movement* **2015**, *16*, 52-59.

27. Viljoen, C.; Janse van Rensburg, D.C.C.; van Mechelen, W.; Verhagen, E.; Silva, B.; Scheer, V.; Besomi, M.; Gajardo-Burgos, R.; Matos, S.; Schoeman, M.; et al. Trail running injury risk factors: a living systematic review. *British journal of sports medicine* **2022**, *56*, 577-587, doi:10.1136/bjsports-2021-104858.

28. McGowan, V.; Hoffman, M.D. Characterization of medical care at the 161-km Western States Endurance Run. *Wilderness & Environmental Medicine* **2015**, *26*, 29-35, doi:10.1016/j.wem.2014.06.015.

29. Hoffman, M.; Pasternak, A.; Rogers, I.; Khodaee, M.; Hill, J.; Townes, D.; Scheer, B.; Krabak, B.; Basset, P.; Lipman, G. Medical Services at Ultra-Endurance Foot Races in Remote Environments: Medical Issues and Consensus Guidelines. *Sports Medicine* **2014**, *44*, 1055-1069, doi:10.1007/s40279-014-0189-3.

30. Clarsen, B.; Myklebust, G.; Bahr, R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire. *British Journal of Sports Medicine* **2013**, *47*, 495-502.

31. Bahr, R.; Clarsen, B.; Derman, W.; Dvorak, J.; Emery, C.A.; Finch, C.F.; Hägglund, M.; Junge, A.; Kemp, S.; Khan, K.M.; et al. International Olympic Committee Consensus Statement: Methods for Recording and Reporting of Epidemiological Data on Injury and Illness in Sports 2020 (Including the STROBE Extension for Sports Injury and Illness Surveillance (STROBE-SIIS)). *Orthopaedic journal of sports medicine* **2020**, *8*, 2325967120902908, doi:10.1177/2325967120902908.

32. Dixon, S.J.; Collop, A.C.; Batt, M.E. Surface effects on ground reaction forces and lower extremity kinematics in running. / Les effets du type de sol sur la force de reaction au sol et la cinematique des membres inferieurs dans la course de fond. *Medicine & Science in Sports & Exercise* **2000**, *32*, 1919-1926.

33. Chen, T.C.; Nosaka, K.; Wu, C.-C. Effects of a 30-min running performed daily after downhill running on recovery of muscle function and running economy. *Journal Of Science And Medicine In Sport* **2008**, *11*, 271-279.

34. Babí Lladós, J.; Inglés Yuba, E.; Cumellas Ruiz, L.; Farías Torbidoni, E.I.; Seguí Urbaneja, J.; Labrador Roca, V. Runner's profile and propensity to sports injury / El perfil de los corredores y su propension al accidente deportivo. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte* **2018**, *18*, 737-752.

35. Bittencourt, N.F.N.; Meeuwisse, W.H.; Mendonça, L.D.; Nettel-Aguirre, A.; Ocarino, J.M.; Fonseca, S.T. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition-narrative review and new concept. *British journal of sports medicine* **2016**, *50*, 1309-1314, doi:10.1136/bjsports-2015-095850.

Chapter 4

Discussion

4. Introduction

Chapter 4 consists of a discussion, clinical and research recommendations, strengths, and limitations, and finally concluding statements.

4.1 Discussion

To my knowledge, my study is one of only three studies that focused on South African trail runners training for a specific race (Viljoen et al., 2021a, Viljoen et al., 2021b), and one of only seven studies to include training associated injury outcomes (Malliaropoulos et al., 2015, Hespanhol Junior et al., 2017, Matos et al., 2020, Matos et al., 2021, Viljoen et al., 2021a, Gajardo-Burgos et al., 2021, Viljoen et al., 2021b).

In my masters study the set objectives were answered: 1) the retrospective annual incidence was 19.92/100 athlete-years, 2) the point prevalence was 4.4%, 3) injuries most commonly occurred at the lower extremity (95%), specifically the lower leg (26%), followed by the thigh (22%) and ankle/foot (13%), 4) the most common tissue type injury was muscle and tendon (60%) and the most common types of pathology included: injury of the muscle (36%), tendinopathy (24%) and joint sprain (9%), and lastly, 5) no RRI risk factors were identified.

These findings coincides with other studies done on trail running-related injuries, but it should also be kept in mind that although most injuries occur in the lower limb, injuries may still occur in other body regions such as reported in the study on Greek trail running athletes that described the lower back (43%) as the most frequently described body region injured (Malliaropoulos et al., 2015). It should also be mentioned that this study was done mainly on ultramarathoners and that the injury profile for non-ultramarathoners may differ from that seen in my study. My masters study is first to examine the two weeks prior the event and thus cannot be equated to other literature.

Tissue and pathology type

In my masters study, tendon/muscle was the primary type of tissue injured described amid all consenting race entrants in the one year (60%) and two weeks (58%) prior to the event. This finding is similar to the findings of the South African (44%) and the Dutch (28%) trail running athletes (Hespanhol Junior et al., 2017, Viljoen et al., 2021a).

The most common type of pathology described was injuries involving muscle (36%) amid all race entrants in my study, trailed by tendinopathy (24%) and joint sprains (9%). This concurs with the findings of the literature that mentioned injuries involving muscle (28%) as the most common type of tissue injured, trailed by injuries involving tendons (24%) and injuries involving ligaments (7%) (Hespanhol Junior et al., 2017). My findings are further reinforced by the study on South African trail running athletes that described injuries involving tendons (28%) as the most frequently injured type of tissue, trailed by sprains (20%) and injuries involving muscle (16%) (Viljoen et al., 2021a). This also corresponds with my findings from the two weeks prior to the race: tendinopathy (33%), injury involving muscle (25%) and joint sprain (17%). This is noteworthy as running requires recurring lower extremity movements where muscles are forced to absorb ground reaction forces (Dixon et al., 2000). Trail running demands enhanced eccentric control, specifically during sheer declines, which may end in additional muscle harm. This distinctive display of repetitive ground force absorption and enhanced eccentric control could add to the development of injuries including muscles and tendons reported among trail running athletes (Chen et al., 2008).

Joint sprains only accounted for 9% of injuries described. This disparity from the 20.0% seen in the retrospective study may be because race entrants prepared for another race distance, geographical region and elevation variations (Viljoen et al., 2021a). Injury information from the two weeks prior to the race demonstrated similar findings for joint sprains (17%) as found by Viljoen et al., (2021a); one hypothesis may be that approaching the race date, race entrants ran frequently on trails in training for the upcoming event as both races took place on trails and runners will want to prepare for the specific terrains expected in the race (Viljoen et al., 2021a).

Associated injury risk factors

As reported in *Chapter 3,* my study yielded no statistically significant related injury risk factors for sustaining a RRI during the year prior the 2021 Mac Mac Ultra. This differs from other studies that investigated and identified associated injury risk factors that included: disregarding a warm-up, training without a structured running program, regularly running on asphalt, double running sessions per day, higher weekly running distances, distinct race terrains, longer race distance entered, six years or more running experience, physical labour occupations, history of RRI, and history of allergies or chronic disease (Malliaropoulos et al., 2015, Matos et al., 2021, Viljoen et al., 2021b). Furthermore, specifically in women, menstrual dysfunction was identified as a risk factor for bone stress injuries (Hutson et al., 2021). This difference seen

might be that these studies included larger sample sizes, took place different geographical setting and investigate different study populations compared to my study and therefore their results will differ from my study.

My study had a representative but small sample size and due to this reason not all variables could be included in the univariate analysis, this may have led to lack of possible associated injury risk factors. It is noteworthy that injury is a complex and developing occurrence and needs to be investigated in this context. Complex problems are defined as an evolving event that arise due to nonlinear interactions between multilevel variables (Bittencourt et al., 2016), thus to analyse an injury a complex system approach is needed by understanding and identifying a "web of determinants" as seen *in* ***Figure 3*** (Bittencourt et al., 2016). Thus, in the future, studies with larger sample sizes may benefit from conducting a multivariate analysis to include the complex nature of injury. As my study did not have a large study sample a multivariate analysis could not be included thus, injury could not be investigated as the complex problem that it presents as, and risk factors may have been missed.

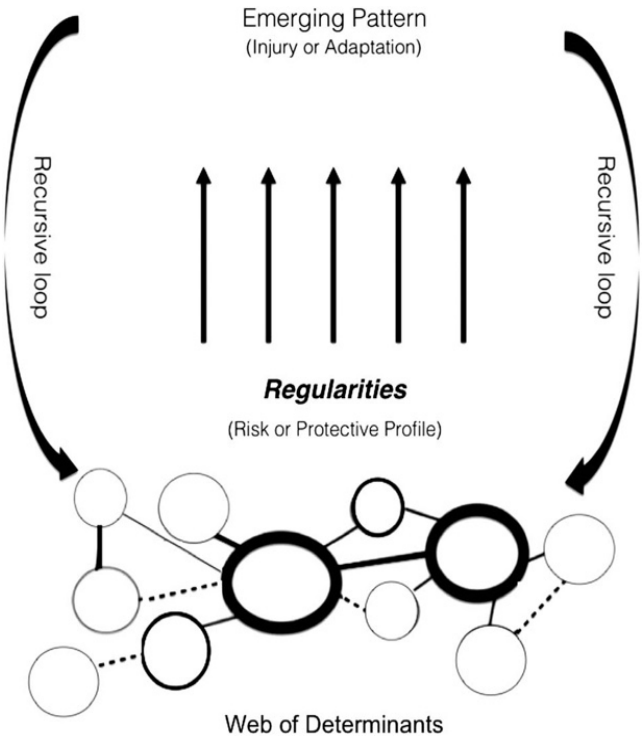


Figure 3: Representations of the complex model for sports injury, the web of determinants, which comprises contributing units with various weights (Bittencourt, Meeuwisse, Mendonça, et al. 2016)

4.2 Clinical recommendations

The results from this study can assist HCPs in developing injury risk management tactics for trail runners preparing towards a specific trail run race.

4.2.1 We recommend that HCPs consider the intrinsic and extrinsic factors of each athlete during the development and implementation of injury risk prevention strategies.

4.2.2 Healthcare professionals should focus on the lower extremity, particularly foot, lower leg, ankle and thigh, when designing injury risk management strategies.

4.2.3 Healthcare professionals should be aware that muscle injuries, tendinopathies and joint sprains were the most frequently reported pathology types and consider this when designing injury risk management strategies.

4.2.4 Healthcare professionals should consider that many intrinsic and extrinsic variables in combination may contribute to sustaining an injury and they should not only focus on individual factors when developing and implementing injury risk prevention strategies.

4.3 Research recommendations

4.3.1 Future studies will benefit from for larger sample sizes to ensure that a multivariate analysis of possible injury risk factors may be completed.

4.3.2 Future studies can be enhanced by a prospective cohort design to follow race entrants through their training period to minimise recall bias and report on injuries as they occur, as well as identify delayed onset injuries.

4.3.3 Separate studies on injuries occurring in competition or in training are required to increase the granularity of data relating to race conditions being different from training conditions.

4.3.4 More studies investigating the two weeks before the competition should be conducted, as many runners may change their training habits closer to the race.

Furthermore, this study may be used in the Physiotherapy profession to conduct educational sessions for other HCPs and Physiotherapist to broaden their clinical experience when treating and assisting trail runners in preparing for specific trail running races. Furthermore, Educational workshops can be hosted to trail runners in addition to their physical training to further educate them on proper training approaches as well as what to look out for regarding injuries and prevention of injuries.

4.4 Limitations

The findings of my study should be studied in the perspective of the restrictions such as recollection bias of the cross-sectional study that utilised self-reporting of information based on injuries that occurred during the previous year. The small point prevalence might be due to trail running athletes fearing ineligibility after completion of the pre-race medical screening process. Future studies should target prospective cohort study design with regular follow-ups to reduce recollection bias, as well as report on delayed onset injuries. Participants might have misinterpreted some of the medical terminology describing pathology of injury in this questionnaire. Furthermore, participants may not have interpreted body areas correctly, thus a body chart may be added in the future. The absence of recognised risk factors in regards to injury may be due to the sample size. Race entrants with serious injuries leaving them incapable of participating, were absent at race registration and unable to complete the screening process, as a result those injuries are absent from the study. Finally, it is notable that this study investigated a specific populace of trail running athletes training for a particular event in a harsh province of South Africa. Hence, the findings of this study should not be generalised to trail running athletes training for events in various environmental locations (desert, forest etc.).

4.5 Strengths

A strong characteristic of my study is that 76.0% of all the 2021 Mac Mac Ultra race entrants consented to partake in the study and were an established demonstrative example of the entire populace. This study tackles the substantial scarceness of trail running research regarding the epidemiology and clinical characteristics of injuries in preparing for trail run events. A particular strength of the study is the contribution of new insights pertaining to the two weeks prior to a race.

4.6 Conclusion

One out of five race entrants, entered for the Mac Mac Ultra race, mentioned at least one injury in the previous year before the race. Race entrants training for the 2021 Mac Mac Ultra race described RRIs frequently involving the lower extremity, particularly the foot, thigh, ankle, and lower leg. Additionally, my study recognised that trail running athletes might consider competing irrespective of injuries. This stresses the obligation to detect risk factors regarding injury to help in developing injury prevention programs, as the incidence of developing injuries in trail run events could mean distressing consequences.

4.7 References

Bittencourt, N. F. N., Meeuwisse, W. H., Mendonça, L. D., Nettel-Aguirre, A., Ocarino, J. M. & Fonseca, S. T. 2016. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition-narrative review and new concept. *British journal of sports medicine,* 50**,** 1309-1314.

Chen, T. C., Nosaka, K. & Wu, C.-C. 2008. Effects of a 30-min running performed daily after downhill running on recovery of muscle function and running economy. *Journal Of Science And Medicine In Sport,* 11**,** 271-279.

Dixon, S. J., Collop, A. C. & Batt, M. E. 2000. Surface effects on ground reaction forces and lower extremity kinematics in running. / Les effets du type de sol sur la force de reaction au sol et la cinematique des membres inferieurs dans la course de fond. *Medicine & Science in Sports & Exercise,* 32**,** 1919-1926.

Gajardo-Burgos, R., Monrroy-Uarac, M., Barría-Pailaquilén, R. M., Norambuena-Noches, Y., Van Rensburg, D. C. J., Bascour-Sandoval, C. & Besomi, M. 2021. Frequency of Injury and Illness in the Final 4 Weeks before a Trail Running Competition. *International journal of environmental research and public health,* 18.

Hespanhol Junior, L., Van Mechelen, W. & Verhagen, E. 2017. Health and Economic Burden of Running-Related Injuries in Dutch Trailrunners: A Prospective Cohort Study. *Sports Medicine,* 47**,** 367-377.

Hutson, M. J., O'donnell, E., Petherick, E., Brooke-Wavell, K. & Blagrove, R. C. 2021. Incidence of bone stress injury is greater in competitive female distance runners with menstrual disturbances independent of participation in plyometric training. *Journal of Sports Sciences,* 39**,** 2558-2566.

Malliaropoulos, N., Mertyri, D. & Tsaklis, P. 2015. Prevalence of Injury in Ultra Trail Running. *Human Movement,* 16**,** 52-59.

Matos, S., Clemente, F. M., Silva, R. & Cancela Carral, J. M. 2020. Variations of Workload Indices Prior to Injuries: A Study in Trail Runners. *International journal of environmental research and public health,* 17.

Matos, S., Silva, B., Clemente, F. M. & Pereira, J. 2021. Running-related injuries in Portuguese trail runners: a retrospective cohort study. *The Journal of sports medicine and physical fitness,* 61**,** 420-427.

Viljoen, C. T., Janse Van Rensburg, D. C., Jansen Van Rensburg, A., Booysen, E., Chauke, S., Coetzee, P., Hurlimann, A., Jooste, M., Nibe, Y., Schulenburg, C., Korkie, E.,

Ramagole, D., Grant, C. & Cronje, T. 2021a. One in four trail running race entrants sustained an injury in the 12 months training preceding the 2019 SkyRun race. *Physical Therapy in Sport,* 47**,** 120-126.

Viljoen, C. T., Sewry, N., Schwellnus, M. P., Janse Van Rensburg, D. C., Swanevelder, S. & Jordaan, E. 2021b. Independent Risk Factors Predicting Gradual Onset Injury in 2824 Trail Running Race Entrants: SAFER XVIII Study. *Wilderness & Environmental Medicine,* 32**,** 293-301.

Appendices

Appendix A: University of Pretoria Ethical Approval Letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.
- FWA 00002567, Approved dd 18 March 2022 and Expires 18 March 2027.
- IORG #: IORG0001762 OMB No. 0990-0278 Approved for use through August 31, 2023.

Faculty of Health Sciences **Research Ethics Committee**

20 June 2023

Approval Certificate
Annual Renewal

Dear Mrs MD Jooste,

Ethics Reference No.: 404/2022 – Line 1
Title: The epidemiology, clinical characteristics, and associated injury risk factors among trail runners entered for the 2021 Mac Mac Ultra Race

The **Annual Renewal** as supported by documents received between 2023-05-23 and 2023-06-14 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2023-06-14 as resolved by its quorate meeting.

Please note the following about your ethics approval:
- Renewal of ethics approval is valid for 1 year, subsequent annual renewal will become due on 2024-06-20.
- Please remember to use your protocol number (404/2022) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Professor C Kotzé
MBChB, DMH, MMed(Psych), FCPsych, Phd
***Acting Chairperson**: Faculty of Health Sciences Research Ethics Committee*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

Appendix B: Custodian of Data Letter

Professor Christa Janse van Rensburg
MD (PhD), MMed MSc, MBChB, FACSM, FFIMS
Head: Sports Medicine
Faculty of Health Sciences
University of Pretoria
South Africa
8 March 2022

To: Chair: Masters Committee/ Research Ethics Committee

University of Pretoria

LETTER OF PERMISSION TO ACCESS DATA FOR RESEARCH

This letter is to confirm that Prof Christa Janse van Rensburg of Section Sports Medicine, at the University of Pretoria is the custodian of the dataset and principal investigator of the project with the title "**Reducing Injuries and Illness at Adventure Sports Events: A 10-Year Longitudinal Study (2018-2028)**". This study has Research Ethics clearance from the Faculty of Health Sciences Research Ethics Committee at the University of Pretoria (REC reference number: 460/2018).

A master's student, Mignette Jooste (student number: 16037155), will be conducting a study, in partial fulfilment of an MPhysT degree at the University of Pretoria, on a sub-component of the study above. The focus of this study will be: **The Epidemiology, Clinical Characteristics, and Associated Injury Risk Factors Among Trail Runners Entered for the 2021 Mac Mac Ultra Race.**

I hereby give permission that the student can conduct novel research on the raw dataset, and therefore can access the data that were collected for the study.

Please feel free to contact me if any further information is required.

Yours sincerely

Prof. Christa Janse van Rensburg (MD (PhD), MMed MSc, MBChB, FACSM, FFIMS)
Full Professor: Sports Medicine
Faculty of Health Sciences
University of Pretoria
South Africa
Email: christa.jansevanrensburg@up.ac.za

Appendix C: Letter of Statistical Support

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Denkleiers • Leading Minds • Dikgopolo tša Dihlalefi

DEPARTMENT OF STATISTICS

LETTER OF STATISTICAL SUPPORT

Date: 31st January 2022

This letter is to confirm that ***Mignette Jooste***, studying at the University of Pretoria, discussed the project with the title "***Epidemiology, clinical characteristics, and associated injury risk factors among trail runners entered for the 2021 Mac Mac ultra race.***" with me.

I hereby confirm that I am aware of the project and also undertake to assist with the statistical analysis of the data generated from the project. The aim of the study is to determine the epidemiology (retrospective annual incidence and point prevalence), clinical characteristics (anatomical site, body area, tissue type, pathology type and severity) and identify any associated injury risk factors among trail runners entered for the 2021 Mac Mac Ultra race.

The sample consists of a total population sample comprising of all trail runners who gave consent entered for the 2021 Mac Mac Ultra, in four different race categories (46km, 80km, 161km and 322km)

The data analysis will consist of descriptive statistics such as mean, median, standard deviations, frequencies, proportions etc. to describe the results and graphical representations can be made were applicable to assist in visualizing aspects of the data. Inferential statistics will include tests which compare results between the injured and non-injured participants and may include tests like the Chi-square test and the independent t-test (or the nonparametric alternatives). Regression analysis may also be included to identify any possible risk factors. All statistical tests will be performed at a 5% level of significance.

Tanita Botha
Department of Statistics
Internal Statistical Consultation Service
Tanita.Botha@up.ac.za

Appendix D: Permission letter from Race Organiser

371 Farenden Road, Arcadia, Pretoria

www.macmacultra.com

info@macmacultra.com

083 3999 564

Date: 12 January 2022

To whom it may concern:

RE: THE EPIDEMIOLOGY, CLINICAL CHARACTERISTICS AND ASSOCIATED INJURY RISK FACTORS AMONG TRAIL RUNNERS ENTERED FOR THE 2021 MAC MAC ULTRA.

I hereby give permission to Carel Viljoen and all the individuals involved from the *DEPARTMENT OF PHYSIOTHERAPY (University of Pretoria)*, to conduct research about ILLNESS & INJURY at the MAC MAC ULTRA 2021.

For any more queries do not hesitate to contact me.

Kind regards

Eloff Hoffman

EVENT ORGANISER

Appendix E: Proof of Publication

applied sciences

an Open Access Journal by MDPI

CITESCORE 4.5

IMPACT FACTOR 2.7

CERTIFICATE OF PUBLICATION

Certificate of publication for the article titled:

One in Five Trail Running Race Entrants Sustained an Injury in the 12 Months Training Period before the 2021 Mac Mac Ultra Race

Authored by:

Mignette Jooste; Dina C. Janse van Rensburg; Volker Scheer; Audrey Jansen van Rensburg; Dimakatso Ramagole; Tanita Botha;
Carel Viljoen

Published in:

Appl. Sci. **2023**, Volume 13, Issue 17, 9586

MDPI Academic Open Access Publishing since 1996

Basel, August 2023

Appendix F: Online Pre-race Medical Screening Questionnaire

Mac Mac Ultra Pre-race 2021

Survey Flow

Block: Intro (1 Question)
Standard: Demographic data (16 Questions)
Block: Training data (4 Questions)
Block: Inj/ill/both/none?? (1 Question)

Branch: New Branch
If
If Do you have a current have an INJURY or ILLNESS? BOTH an injury and illness Is Selected

Block: OSTRC both (4 Questions)
Block: Injury 1 (7 Questions)

Branch: New Branch
If
If Do you have ANOTHER INJURY to record? Yes Is Selected

Block: Injury 2 (7 Questions)

Branch: New Branch
If
If Do you have any OTHER INJURY to record? Yes Is Selected

Block: Injury 3 (6 Questions)
Block: Illness 1 (6 Questions)

Branch: New Branch
If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 2 (6 Questions)

Branch: New Branch
If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 3 (5 Questions)
Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Illness 1 (6 Questions)

Branch: New Branch

If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 2 (6 Questions)

Branch: New Branch
If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 3 (5 Questions)
Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Illness 1 (6 Questions)

Branch: New Branch
If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 2 (6 Questions)

Branch: New Branch
If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 3 (5 Questions)
Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Branch: New Branch
If
If Do you have a current have an INJURY or ILLNESS? ILLNESS Is Selected

Block: OSTRC illness (modification) (4 Questions)
Block: Illness 1 (6 Questions)

Branch: New Branch
If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 2 (6 Questions)

Branch: New Branch
If
If Do you have any OTHER ILLNESS to record? Yes Is Selected

Block: Illness 3 (5 Questions)
Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Branch: New Branch
If
If Do you have a current have an INJURY or ILLNESS? INJURY Is Selected

Block: OSTRC injury (modification) (4 Questions)
Block: Injury 1 (7 Questions)

Branch: New Branch
If
If Do you have ANOTHER INJURY to record? Yes Is Selected

Block: Injury 2 (7 Questions)

Branch: New Branch
If
If Do you have any OTHER INJURY to record? Yes Is Selected

Block: Injury 3 (6 Questions)
Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Block: Consent! (1 Question)

EndSurvey:

Page Break

Start of Block: Intro

Q110 This medical questionnaire is compulsory as part of the registration process for the 2021 Mac Mac Ultra. All injury and illness information, as well as running/training data will be kept confidential, and will only be used in emergencies. It also forms part of an anonymous survey to guide future injury prevention strategies and medical interventions amongst trail runners.

○ I have read the above (1)

End of Block: Intro

Start of Block: Demographic data

Q111 Initials and Surname

_____

_____

_____

_____

_____

Q112 Email address

_____

_____

_____

_____

_____

Q118 For which Mac Mac Ultra **race distance** did you enter?

- ○ 200 miles (6)
- ○ 100 miles (1)
- ○ 50 miles (3)
- ○ 46 km (4)

Q114 Age

_____

Q115 Sex

- ○ Male (1)
- ○ Female (2)

Q116 What is your current **height (cm)?**

_____

Q117 What is your current **weight (kg)?**

_____

Q119 On what **surfaces** do you train/run?

	Often (1)	Sometimes (2)	Rarely (3)
Dirt roads (trails) (1)	○	○	○
Street (tarred/paved surfaces) (2)	○	○	○
Grass (3)	○	○	○
Athletic track (tartan) (4)	○	○	○
Treadmill (5)	○	○	○

Q120 For what time period have you been actively **participating in RUNNING** as a sport?

▼ less than 1 year (2) ... more than 10 years (12)

Q121 For what time period have you been actively **participating in TRAIL RUNNING** as a sport?

▼ less than 1 year (2) ... more than 10 years (12)

Q125 Did you sustain **any running-related injuries** in the PAST TWELVE MONTHS?

○ Yes (1)

○ No (2)

Q126 If yes, do you still at this stage experience similar symptoms from this injury?

- ○ Yes (1)
- ○ No (2)

Q127 Please specify the **DIAGNOSIS** of your injury (or location of symptoms if diagnosis was not made)

- ☐ Diagnosis (1) _____
- ☐ Location of injury (2) _____

Q128 Are you suffering from any **CHRONIC DISEASES** i.e. hypertension, asthma, diabetes, cholesterol?

- ○ Yes (1)
- ○ No (2)

Q87 **If yes**, please list your chronic diseases

_____

Q129 Please list all other **MEDICATIONS** and/or **SUPPLEMENTS** that you currently use.

_____

End of Block: Demographic data

Start of Block: Training data

Q88 The following questions refer to the **AVERAGES OF THE PAST 12 MONTHS**

On average, how many **running sessions** do you do **per week**?

▼ 0 (1) ... more than 7 (9)

Q58 On average, how many of your weekly **running sessions** are **run on TRAILS**?

▼ 0 (1) ... More than 7 (9)

Q82 What is your **average weekly vertical gain (m)**?

▼ 0 - 500 m (1) ... > 4000 m (9)

Q60 What weekly **cross training** did you do in the past 12 MONTHS and on average **how many sessions per week?**
Cycling : _____ (1)
Strength/weight training : _____ (2)
Rowing : _____ (3)
Swimming : _____ (4)
Pilates : _____ (5)
Functional training (High intensity interval training or Crossfit) : _____ (6)
Other sports (squash, tennis, soccer etc.) : _____ (7)
None : _____ (8)
Total : _____

End of Block: Training data

Start of Block: Inj/ill/both/none??

Q29 Do you have a current have an INJURY or ILLNESS?

- ○ INJURY (1)
- ○ ILLNESS (2)
- ○ BOTH an injury and illness (3)
- ○ NONE of the above (4)

End of Block: Inj/ill/both/none??

Start of Block: OSTRC both

Q146 Please answer all questions regardless of whether or not you have experienced health problems in the PAST TWO WEEKS.

To what extent have you **MODIFIED YOUR TRAINING OR COMPETITION** due to injury, illness or other health problems during the PAST TWO WEEKS?

- ○ No modification (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q147 To what extent has injury, illness or other health problems affected your **PERFORMANCE** during the PAST TWO WEEKS?

- ○ No effect (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q148 To what extent have you **experienced symptoms/health complaints** during the PAST TWO WEEKS?

- ○ No symptoms/health complaints (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q149 To what extent have you experienced **PAIN** related to your sport during the PAST TWO WEEKS?

- ○ No pain (1)
- ○ Mild pain (2)
- ○ Moderate pain (3)
- ○ Severe pain (4)
- ○ Could not participate at all (5)

End of Block: OSTRC both

Start of Block: Injury 1

Q7 **INJURY 1:** Please select the box that best describes the **LOCATION** of your injury. If the injury involves several locations please select the main area.
If you have **multiple injuries** please complete a **separate registration** of each one.

- ○ Head/face (1)
- ○ Neck (2)
- ○ Shoulder (including clavicle) (3)
- ○ Upper arm (4)
- ○ Elbow (5)
- ○ Forearm (6)
- ○ Wrist (7)
- ○ Hand/fingers (8)
- ○ Chest/ribs (9)
- ○ Abdomen (10)
- ○ Thoracic spine (11)
- ○ Lumbar spine (12)
- ○ Pelvis/buttock (13)
- ○ Hip/groin (14)
- ○ Thigh (front - quadricep) (15)
- ○ Thigh (back - hamstring) (16)
- ○ Knee (17)
- ○ Lower leg (18)
- ○ Ankle (19)
- ○ Foot/toes (20)

Q8 Please select a box that best describes your **TYPE OF INJURY.**

○ Concussion (symptoms like disorientation, dizziness, loss of memory, nausea or vomiting due to a blow to the head) (1)

○ Fracture (traumatic - broken bone caused by sudden impact) (2)

○ Stress fracture (overuse - fracture in a weight bearing bone caused by repetitive stress (e.g. running), a stress fracture in one of the small bones in the foot will typically cause

severe pain at the beginning of a run, moderate pain during the run and severe pain at the end and after the run) (3)

○ Other bone injuries (4)

○ Dislocation, subluxation (the total or partial displacement or misalignment of bones in a joint, most often caused by a sudden impact to the joint) (5)

○ Tendon rupture (tearing of a tendon that occurs when the forces placed upon the tendon exceed its tensile strength) (6)

○ Tendinosis/tendinopathy (all non-inflammatory and inflammatory conditions affecting a tendon, "tendinitis") (7)

○ Ligamentous rupture (tearing of the bands of fibrous tissue connecting bones or cartilages, serving to support and strengthen joints) (8)

○ Sprain (wrenching or twisting of a joint, with partial rupture of its ligaments, accompanied by severe pain, impaired function, swelling, heat and discolouration of the skin) (9)

○ Lesion of meniscus or cartilage (injuries of meniscus [knee] or joint surfaces) (10)

○ Muscle strain (11)

○ Muscle rupture/tear (12)

○ Contusion/haematoma/bruise (13)

○ Arthritis/synovitis/bursitis (inflammation of any part of a joint or structures near the joint, characterize by pain on movement, tenderness, heat and swelling) (14)

○ Fasciitis/aponeurosis injury (inflammation or injury of a sheet like tendinous expansion, e.g. plantar fasciitis) (15)

○ Impingement (compression of a nerve, blood vessel, tendon, ligament or muscle through a constricted space, e.g. sciatica) (16)

○ Skin laceration/cut/lesion (17)

○ Skin abrasion/chafing (18)

○ Dental injury/broken tooth (19)

○ Nerve injury/spinal cord injury (20)

○ Muscle cramps or spasm (21)

- ○ I don't know (22)
- ○ Other (please specify) (23)

_____

Q9 **Who** made the **diagnosis** of your injury?

- ○ Doctor (1)
- ○ Physiotherapist (2)
- ○ Other health care professional (3)
- ○ Coach (4)
- ○ Self-diagnosed (5)

Q10 Did your injury have a **GRADUAL** or **SUDDEN** onset?

- ○ Gradual (1)
- ○ Sudden (2)

Q11 Was the **injury due to a specific action?** (fall, jump, landing, increased pace, overstretch, collision etc.)

- ○ Yes (please specify the action) (1)

_____

- ○ No (2)

Q14 Please state the **NUMBER OF DAYS** that you had to completely **miss training/races** due to this injury.

_____

Q15 Do you have **ANOTHER INJURY** to record?

- ○ Yes (1)
- ○ No (2)

End of Block: Injury 1

Start of Block: Injury 2

Q84 **INJURY 2:**
Please select the box that best describes the **LOCATION** of your injury. If the injury

involves several locations please select the main area.
If you have **multiple injuries** please complete a **separate registration** of each one.

- ○ Head/face (1)
- ○ Neck (2)
- ○ Shoulder (including clavicle) (3)
- ○ Upper arm (4)
- ○ Elbow (5)
- ○ Forearm (6)
- ○ Wrist (7)
- ○ Hand/fingers (8)
- ○ Chest/ribs (9)
- ○ Abdomen (10)
- ○ Thoracic spine (11)
- ○ Lumbar spine (12)
- ○ Pelvis/buttock (13)
- ○ Hip/groin (14)
- ○ Thigh (front - quadricep) (15)
- ○ Thigh (back - hamstring) (16)
- ○ Knee (17)
- ○ Lower leg (18)
- ○ Ankle (19)
- ○ Foot/toes (20)

Q85 Please select a box that best describes your **TYPE OF INJURY.**

- ○ Concussion (symptoms like disorientation, dizziness, loss of memory, nausea or vomiting due to a blow to the head) (1)
- ○ Fracture (traumatic - broken bone caused by sudden impact) (2)
- ○ Stress fracture (overuse - fracture in a weight bearing bone caused by repetitive stress (e.g. running), a stress fracture in one of the small bones in the foot will typically cause

severe pain at the beginning of a run, moderate pain during the run and severe pain at the end and after the run) (3)

○ Other bone injuries (4)

○ Dislocation, subluxation (the total or partial displacement or misalignment of bones in a joint, most often caused by a sudden impact to the joint) (5)

○ Tendon rupture (tearing of a tendon that occurs when the forces placed upon the tendon exceed its tensile strength) (6)

○ Tendinosis/tendinopathy (all non-inflammatory and inflammatory conditions affecting a tendon, "tendinitis") (7)

○ Ligamentous rupture (tearing of the bands of fibrous tissue connecting bones or cartilages, serving to support and strengthen joints) (8)

○ Sprain (wrenching or twisting of a joint, with partial rupture of its ligaments, accompanied by severe pain, impaired function, swelling, heat and discolouration of the skin) (9)

○ Lesion of meniscus or cartilage (injuries of meniscus [knee] or joint surfaces) (10)

○ Muscle strain (11)

○ Muscle rupture/tear (12)

○ Contusion/haematoma/bruise (13)

○ Arthritis/synovitis/bursitis (inflammation of any part of a joint or structures near the joint, characterize by pain on movement, tenderness, heat and swelling) (14)

○ Fasciitis/aponeurosis injury (inflammation or injury of a sheet like tendinous expansion, e.g. plantar fasciitis) (15)

○ Impingement (compression of a nerve, blood vessel, tendon, ligament or muscle through a constricted space, e.g. sciatica) (16)

○ Skin laceration/cut/lesion (17)

○ Skin abrasion/chafing (18)

○ Dental injury/broken tooth (19)

○ Nerve injury/spinal cord injury (20)

○ Muscle cramps or spasm (21)

- ○ I don't know (22)
- ○ Other (please specify) (23)

_____

Q86 **Who** made the **diagnosis** of your injury?

- ○ Doctor (1)
- ○ Physiotherapist (2)
- ○ Other health care professional (3)
- ○ Coach (4)
- ○ Self-diagnosed (5)

Q87 Did your injury have a **GRADUAL** or **SUDDEN** onset?

- ○ Gradual (1)
- ○ Sudden (2)

Q88 Was the **injury due to a specific action?** (fall, jump, landing, increased pace, overstretch, collision etc.)

- ○ Yes (please specify the action) (1)

_____

- ○ No (2)

Q89 Please state the **NUMBER OF DAYS** that you had to completely **miss training/races** due to this injury.

_____

Q90 Do you have any **OTHER INJURY** to record?

- ○ Yes (1)
- ○ No (2)

End of Block: Injury 2

Start of Block: Injury 3

Q100 **INJURY 3:** Please select the box that best describes the **LOCATION** of your injury. If the injury involves several locations please select the main area.
If you have **multiple injuries** please complete a **separate registration** of each one.

- ○ Head/face (1)
- ○ Neck (2)
- ○ Shoulder (including clavicle) (3)
- ○ Upper arm (4)
- ○ Elbow (5)
- ○ Forearm (6)
- ○ Wrist (7)
- ○ Hand/fingers (8)
- ○ Chest/ribs (9)
- ○ Abdomen (10)
- ○ Thoracic spine (11)
- ○ Lumbar spine (12)
- ○ Pelvis/buttock (13)
- ○ Hip/groin (14)
- ○ Thigh (front - quadricep) (15)
- ○ Thigh (back - hamstring) (16)
- ○ Knee (17)
- ○ Lower leg (18)
- ○ Ankle (19)
- ○ Foot/toes (20)

Q101 Please select a box that best describes your **TYPE OF INJURY.**

○ Concussion (symptoms like disorientation, dizziness, loss of memory, nausea or vomiting due to a blow to the head) (1)

○ Fracture (traumatic - broken bone caused by sudden impact) (2)

○ Stress fracture (overuse - fracture in a weight bearing bone caused by repetitive stress (e.g. running), a stress fracture in one of the small bones in the foot will typically cause

severe pain at the beginning of a run, moderate pain during the run and severe pain at the end and after the run) (3)

○ Other bone injuries (4)

○ Dislocation, subluxation (the total or partial displacement or misalignment of bones in a joint, most often caused by a sudden impact to the joint) (5)

○ Tendon rupture (tearing of a tendon that occurs when the forces placed upon the tendon exceed its tensile strength) (6)

○ Tendinosis/tendinopathy (all non-inflammatory and inflammatory conditions affecting a tendon, "tendinitis") (7)

○ Ligamentous rupture (tearing of the bands of fibrous tissue connecting bones or cartilages, serving to support and strengthen joints) (8)

○ Sprain (wrenching or twisting of a joint, with partial rupture of its ligaments, accompanied by severe pain, impaired function, swelling, heat and discolouration of the skin) (9)

○ Lesion of meniscus or cartilage (injuries of meniscus [knee] or joint surfaces) (10)

○ Muscle strain (11)

○ Muscle rupture/tear (12)

○ Contusion/haematoma/bruise (13)

○ Arthritis/synovitis/bursitis (inflammation of any part of a joint or structures near the joint, characterize by pain on movement, tenderness, heat and swelling) (14)

○ Fasciitis/aponeurosis injury (inflammation or injury of a sheet like tendinous expansion, e.g. plantar fasciitis) (15)

○ Impingement (compression of a nerve, blood vessel, tendon, ligament or muscle through a constricted space, e.g. sciatica) (16)

○ Skin laceration/cut/lesion (17)

○ Skin abrasion/chafing (18)

○ Dental injury/broken tooth (19)

○ Nerve injury/spinal cord injury (20)

○ Muscle cramps or spasm (21)

- ○ I don't know (22)
- ○ Other (please specify) (23) _____

Q102 **Who** made the **diagnosis** of your injury?

- ○ Doctor (1)
- ○ Physiotherapist (2)
- ○ Other health care professional (3)
- ○ Coach (4)
- ○ Self-diagnosed (5)

Q103 Did your injury have a **GRADUAL** or **SUDDEN** onset?

- ○ Gradual (1)
- ○ Sudden (2)

Q104 Was the **injury due to a specific action?** (fall, jump, landing, increased pace, overstretch, collision etc.)

- ○ Yes (please specify the action) (1) _____
- ○ No (2)

Q105 Please state the **NUMBER OF DAYS** that you had to completely **miss training/races** due to this injury.

_____

End of Block: Injury 3

Start of Block: Illness 1

Q30 **ILLNESS RECORDING:**
Please check the boxes corresponding to the major symptoms you have experienced during the PAST TWO WEEKS. You may select several alternatives.

- ☐ Fever (1)
- ☐ Fatigue/malaise (2)
- ☐ Swollen glands (3)
- ☐ Sore throat (4)
- ☐ Blocked nose/running nose/sneezing (5)
- ☐ Cough (6)
- ☐ Breathing difficulty/tightness (7)
- ☐ Nausea (8)
- ☐ Vomiting (9)
- ☐ Diarrhoea (10)
- ☐ Constipation (11)
- ☐ Abdominal pain (12)
- ☐ Irregular pulse/arrhythmia (13)
- ☐ Chest pain/Angina (14)
- ☐ Other pain (15)
- ☐ Headache (16)

- [ ] Fainting (17)
- [ ] Numbness/pins and needles (18)
- [ ] Sunburn (19)
- [ ] Rash with itchiness (20)
- [ ] Ear symptoms (21)
- [ ] Eye symptoms (22)
- [ ] Symptoms from urinary tract/genitalia (23)
- [ ] Anxiety (24)
- [ ] Depression/sadness (25)
- [ ] Irritability (26)
- [ ] Muscle Cramps – Generalised (unspecific region of the body) (27)
- [ ] Muscle Cramps – Localised (in specific location) (28)
- [ ] Other (please specify) (29) _____

Q35 **Do have a specific diagnosis for your illness? Please specify**

- ○ Yes (please specify) (1) _____
- ○ No (2)

Q36 **Who made the diagnosis of your illness?**

- ○ Doctor (1)
- ○ Physiotherapist (2)
- ○ Other health care professional (3)
- ○ Coach (4)
- ○ Self-diagnosed (5)

Q38 **How was your illness treated or managed?**

- ☐ Self-medicated (1)
- ☐ Antibiotics (2)
- ☐ Referral to other health care professional (3)
- ☐ Other drug therapies (4)

Q40 **Please state the NUMBER OF DAYS that you had to completely miss training/races due to this illness.**

_____

Q41 **Do you have any OTHER ILLNESS to record?**

- ○ Yes (1)
- ○ No (2)

End of Block: Illness 1

Start of Block: Illness 2

Q40 **Please check the boxes corresponding to the major symptoms you have experienced during the PAST TWO WEEKS. You may select several alternatives.**

- ☐ Fever (1)
- ☐ Fatigue/malaise (2)
- ☐ Swollen glands (3)
- ☐ Sore throat (4)
- ☐ Blocked nose/running nose/sneezing (5)
- ☐ Cough (6)
- ☐ Breathing difficulty/tightness (7)
- ☐ Nausea (8)
- ☐ Vomiting (9)
- ☐ Diarrhoea (10)
- ☐ Constipation (11)
- ☐ Abdominal pain (12)
- ☐ Irregular pulse/arrhythmia (13)
- ☐ Chest pain/Angina (14)
- ☐ Other pain (15)
- ☐ Headache (16)
- ☐ Fainting (17)

- ☐ Numbness/pins and needles (18)
- ☐ Sunburn (19)
- ☐ Rash with itchiness (20)
- ☐ Ear symptoms (21)
- ☐ Eye symptoms (22)
- ☐ Symptoms from urinary tract/genitalia (23)
- ☐ Anxiety (24)
- ☐ Depression/sadness (25)
- ☐ Irritability (26)
- ☐ Muscle Cramps – Generalised (unspecific region of the body) (27)
- ☐ Muscle Cramps – Localised (in specific location) (28)
- ☐ Other (please specify) (29) _____

Q42 **Do have a specific diagnosis for your illness? Please specify**

- ○ Yes (please specify) (1) _____
- ○ No (2)

Q43 **Who made the diagnosis of your illness?**

- ○ Doctor (1)
- ○ Physiotherapist (2)
- ○ Other health care professional (3)
- ○ Coach (4)
- ○ Self-diagnosed (5)

Q45 **How was your illness treated or managed?**

- ☐ Self-medicated (1)
- ☐ Antibiotics (2)
- ☐ Referral to other health care professional (3)
- ☐ Other drug therapies (4)

Q46 **Please state the NUMBER OF DAYS that you had to completely miss training/races due to this illness.**

_____

Q47 **Do you have any OTHER ILLNESS to record?**

- ○ Yes (1)
- ○ No (2)

End of Block: Illness 2

Start of Block: Illness 3

Q48 **Please check the boxes corresponding to the major symptoms you have experienced during the PAST TWO WEEKS. You may select several alternatives.**

- ☐ Fever (1)
- ☐ Fatigue/malaise (2)
- ☐ Swollen glands (3)
- ☐ Sore throat (4)
- ☐ Blocked nose/running nose/sneezing (5)
- ☐ Cough (6)
- ☐ Breathing difficulty/tightness (7)
- ☐ Nausea (8)
- ☐ Vomiting (9)
- ☐ Diarrhoea (10)
- ☐ Constipation (11)
- ☐ Abdominal pain (12)
- ☐ Irregular pulse/arrhythmia (13)
- ☐ Chest pain/Angina (14)
- ☐ Other pain (15)
- ☐ Headache (16)
- ☐ Fainting (17)

- ☐ Numbness/pins and needles (18)
- ☐ Sunburn (19)
- ☐ Rash with itchiness (20)
- ☐ Ear symptoms (21)
- ☐ Eye symptoms (22)
- ☐ Symptoms from urinary tract/genitalia (23)
- ☐ Anxiety (24)
- ☐ Depression/sadness (25)
- ☐ Irritability (26)
- ☐ Muscle Cramps – Generalised (unspecific region of the body) (27)
- ☐ Muscle Cramps – Localised (in specific location) (28)
- ☐ Other (please specify) (29) _____

Q50 **Do have a specific diagnosis for your illness? Please specify**

- ○ Yes (please specify) (1) _____
- ○ No (2)

Q51 **Who made the diagnosis of your illness?**

- ○ Doctor (1)
- ○ Physiotherapist (2)
- ○ Other health care professional (3)
- ○ Coach (4)
- ○ Self-diagnosed (5)

Q53 **How was your illness treated or managed?**

- ☐ Self-medicated (1)
- ☐ Antibiotics (2)
- ☐ Referral to other health care professional (3)
- ☐ Other drug therapies (4)

Q54 **Please state the NUMBER OF DAYS that you had to completely miss training/races due to this illness.**

_____

End of Block: Illness 3

Start of Block: Consent!

Q109 **I hereby consent for my information to be used anonymously in the research study**

- ○ Yes (1)
- ○ No (2)

End of Block: Consent!

Start of Block: OSTRC illness (modification)

Q141 Please answer all questions regardless of whether or not you have experienced health problems in the PAST TWO WEEKS.

To what extent have you **MODIFIED YOUR TRAINING OR COMPETITION** due to illness during the PAST TWO WEEKS?

- ○ No modification (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q142 To what extent has illness affected your **PERFORMANCE** during the PAST TWO WEEKS?

- ○ No effect (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q143 To what extent have you **experienced symptoms/health complaints** during the PAST TWO WEEKS?

- ○ No symptoms/health complaints (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q144 To what extent have you experienced **PAIN** related to your sport during the PAST TWO WEEKS?

- ○ No pain (1)
- ○ Mild pain (2)
- ○ Moderate pain (3)
- ○ Severe pain (4)
- ○ Could not participate at all (5)

End of Block: OSTRC illness (modification)

Start of Block: OSTRC injury (modification)

Q2 Please answer all questions regardless of whether or not you have experienced health problems in the PAST TWO WEEKS.

To what extent have you **MODIFIED YOUR TRAINING OR COMPETITION** due to injury, during the PAST TWO WEEKS?

- ○ No modification (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q3 To what extent has injury affected your **PERFORMANCE** during the PAST TWO WEEKS?

- ○ No effect (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q4 To what extent have you **experienced symptoms/health complaints** during the PAST TWO WEEKS?

- ○ No symptoms/health complaints (1)
- ○ To a minor extent (2)
- ○ To a moderate extent (3)
- ○ To a major extend (4)
- ○ Could not participate at all (5)

Q5 To what extent have you experienced **PAIN** related to your sport during the PAST TWO WEEKS?

- ○ No pain (1)
- ○ Mild pain (2)
- ○ Moderate pain (3)
- ○ Severe pain (4)
- ○ Could not participate at all (5)

End of Block: OSTRC injury (modification)

Appendix G: Informed consent to use participant's data

ICD 1A

PARTICIPANT'S INFORMATION & INFORMED CONSENT DOCUMENT

STUDY TITLE: The epidemiology, clinical characteristics and associated injury risk factors among trail runners entered for the 2021 Mac Mac Race

Principal Investigators: Carel Viljoen, Christa Janse van Rensburg, Tanita Cronje

Institution: University of Pretoria

DAYTIME AND AFTER HOURS TELEPHONE NUMBER(S):

Daytime number/s: 0124206053

Afterhours number: 0845119226

Dear Prospective Participant

1) INTRODUCTION

You are invited to volunteer for a research study. This information in this document is to help you to decide if you would like to participate. Before you agree to take part in this study you should fully understand what is involved. If you have any questions, which are not fully explained in this document, do not hesitate to ask the researcher. You should not agree to take part unless you are completely happy about all the procedures involved.

2) THE NATURE AND PURPOSE OF THIS STUDY

The aim of this study is to evaluate the predisposing risk factors , and injuries associated with trial running entrants of the 2021 Mac Mac race. By doing so we wish to learn more about your demographics, training variables, sport participation, specific injuries acquired before the race *(the cause of this disease)*.

3) EXPLANATION OF PROCEDURES AND WHAT WILL BE EXPECTED FROM PARTICIPANTS.

This study involves answering some questions with regards to the 12 months prior to the race, examination of participation, Performance and specific diagnosis that is associated with injuries will be evaluated.

4) POSSIBLE RISKS AND DISCOMFORTS INVOLVED

There are no medical risks associated with the study.

5) POSSIBLE BENEFITS OF THIS STUDY

Although you may or may not benefit directly. Once injuries and associated risk factors understood and described further studies can be conducted to provide injury prevention models for trial runners competing in trial running events .

6) YOUR RIGHTS AS A RESEARCH PARTICIPANT

Your participation in this trial is entirely voluntary and you can refuse to participate or stop at any time without stating any reason. Your withdrawal will not affect your access to other medical care.

8) ETHICS APPROVAL

This protocol was approved by the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (protocol number: REC: 404/2022).

9) INFORMATION

If I have any questions concerning this study, I should contact:

Christa Janse van Rensburg:

Work tel: 0124206053

Mr CT Viljoen:

Cell :0845119226

10) CONFIDENTIALITY

All information obtained during the course of this study will be regarded as confidential. Each participant that is taking part will be provided with an alphanumeric coded number e.g. A001. This will ensure confidentiality of information so collected. Only the researcher will be able to identify you as a participant. Results will be published or presented in such a fashion that patients remain unidentifiable. No hard copies of your records will be kept since this is an online questionnaire and the information will be stored on the website.

11) CONSENT TO PARTICIPATE IN THIS STUDY

- I confirm that the person requesting my consent to take part in this study has told me about the nature and process, any risks or discomforts, and the benefits of the study.
- I have also received, read and understood the above written information about the study.

- I have had adequate time to ask questions and I have no objections to participate in this study.
- I am aware that the information obtained in the study, including personal details, will be anonymously processed and presented in the reporting of results.
- I understand that I will not be penalised in any way should I wish to discontinue with the study and that withdrawal will not affect my further treatments.
- I am participating willingly.
- I have received a signed copy of this informed consent agreement.

At the end of the online questionnaire, you will be given the chance to give informed consent or not for the use of your data in the research study by clicking the appropriate answer.