DOES A GREATER TRAINING LOAD INCREASE THE RISK OF INJURY AND ILLNESS IN ULTRAMARATHON RUNNERS? – A PROSPECTIVE, DESCRIPTIVE, LONGITUDINAL DESIGN

A DISSERTATION BY NICOLE CRADDOCK (CRDNIC004) IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE MASTER OF SCIENCE IN EXERCISE AND SPORTS PHYSIOTHERAPY FROM THE UNIVERSITY OF CAPE TOWN

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DECLARATION

I, Nicole Craddock (CRDNIC004), hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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(signature)

………08 February 2020………………………………………………

(date)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACWR:	Acute Chronic Workload Ratio
BMI:	Body Mass Index
EWMA:	Exponentially Weighted Moving Averages
IgA:	Immunoglobulin A
NSAID:	Non-Steroidal Anti-Inflammatory Drug
OSTRC:	Oslo Sports Trauma Research Centre
PFPS:	Patellofemoral Pain Syndrome
RPE:	Rating of Perceived Exertion
RRI:	Running-Related Injury
Th1:	Type 1
Th2:	Type 2
UCT:	University of Cape Town
URTI:	Upper Respiratory Tract Infection

GLOSSARY OF TERMS

Absolute load: The "absolute" load refers to the resultant load (i.e. internal and external load) placed on an athlete over the period of a day or week (Gabbett, 2016).

Acute training load: This describes the weekly cumulative training load (Gabbett, 2016).

Acute:chronic workload ratio: The acute chronic workload ratio describes the cumulative weekly load (acute) in comparison to the cumulative monthly (chronic) load (Drew & Finch, 2016). For the purpose of this study, external training load was used to calculate this ratio.

Chronic training load: This is the cumulative training load over a period of three to six weeks. A four week period is mostly commonly used (Gabbett, 2016).

Exponentially weighted moving average: A method of calculation of the ACWR with decreasing weighting given to older values and more weighting given to recent loads towards the end of a four week training period.

$$*EWMA_{today} = Load_{today} * \lambda_{a} + ((1 - \lambda_{a}) * EWMA_{yesterday})$$

External training load: Refers to the load imposed on the athlete including distance, duration, intensity and frequency (Borresen & Lambert, 2009). For the purpose of this study external training load refers to distance ($km.wk^{-1}$).

Illness: *"A new or recurring illness incurred during competition or training receiving medical attention, regardless of the consequences with respect to absence from competition or training"* (Schwellnus et al., 2016, p1044).

Incidence rate: Frequency with which an incidence occurs over a specific period of time (Krug & McNutt, 2016).

Incidence proportion: The number of cases (i.e. injuries) that develop over a specific period of time divided by the whole population at risk at the start (Krug and McNutt, 2016).

Internal training load: This refers to the physiological stress imposed on the athlete at the time of the training sessions (Lambert & Borresen, 2010). For the purpose of this study, internal training load has been defined as duration ($min.wk^{-1}$) times RPE (0-10).

Overuse injuries: *"Any injury with a gradual onset, which influenced performance during competition or training"* (Knobloch, Yoon, & Vogt, 2008, p673).

Relative load: The "relative" load describes the percentage increase in load over a week or even month (Gabbett, 2016). Relative load in our study refers to the exponentially weighted moving average of the acute chronic workload ratio as described above.

Running economy: *"The energy demand for a given velocity of submaximal running"* (Saunders, Pyne, Telford & Hawley, 2004, p465).

Running-related injuries: *"Running-related (training or competition) musculoskeletal pain in the lower limbs that causes a restriction on or stoppage of running (distance, speed, duration, or training) for at least seven days or three consecutive scheduled training sessions, or that requires the runner to consult a physician or other health professional"* (Yamato, Saragiotto, & Lopes, 2015, p377).

Training load: Training load is a combination of both the absolute load (internal and external training load) as well as the relative load (EWMA of the ACWR) experienced by the athlete (Gabbett, 2016).

Ultramarathon: *"A foot race longer than the standard 42.2 km marathon distance"* (Hoffman & Krishnan, 2013, p2939).

Workload: *"The cumulative amount of stress placed on an individual from multiple training sessions and games over a period of time"* (Windt & Gabbet, 2017, p2).

ABSTRACT

Background:

Ultramarathon running has become extremely popular over the years. Despite the numerous health benefits of running, there are also many negative effects of running such as increased risk of musculoskeletal injury and illness. Training loads imposed on an athlete should induce positive physiological adaptations to improve their performance. Monitoring of an athlete's training load has become extremely important in terms of injury prevention. Currently, the relationship between training loads and injury and illness incidence is uncertain. More research is needed in this field to minimise the risk of injury and illness and maximise performance in ultramarathon runners.

Aim:

To determine if there are any associations between injury and illness incidences and training loads among ultramarathon runners in the 12 week period preceding an ultramarathon event and the four week period after the event.

Specific Objectives:

- To describe the incidence rate of overall and region-specific running-related injuries in a population of ultramarathon runners in the 16 week period surrounding an ultramarathon event.
- To describe the incidence rate of illness and illness-related symptoms in a population of ultramarathon runners in the 16 week period surrounding an ultramarathon event.
- To describe the weekly and cumulative training parameters (training volume, training frequency, training intensity, training duration) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.
- To describe the weekly and cumulative absolute training load parameters (internal load, external load) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.
- To describe the weekly relative training load parameters (ACWR) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.

- To determine whether there are any significant differences between the injured and uninjured groups and the ill and healthy groups with regard to: a) mean training parameters; b) mean internal training load; and c) mean external training load, over the 16 week period.
- To identify any significant associations between: a) absolute training load (internal training load; external training load) and injury and illness incidence; and b) relative training load and injury and illness incidence over the 16 week period.

Methods:

A prospective, descriptive, longitudinal study design was conducted in runners who were training for the 2019 Two Oceans Ultramarathon. One hundred and nineteen participants were recruited for this study and tracked over a period of 16 weeks (12 weeks leading up to the Two Oceans Ultramarathon event and for four weeks afterwards). Data was collected once a week via an online logbook. Training parameters measured included weekly average running distance, average duration, average frequency and average session RPE. Injury data included injury counts, the structure injured, the main anatomical location and time-loss from injury. Illness data included illness counts, the main illness-related symptoms and time-loss from illness.

Results:

The overall injury incidence proportion was 31%. The week after the ultramarathon race had the highest injury proportion of 7%. The overall injury incidence was 5 per 1000 training hours. The average time-loss due to injury was three training sessions missed. The overall illness incidence proportion was 66%. The week after the ultramarathon race also had the highest illness proportion of 22%. The overall illness incidence was 16 per 1000 training days. The average time-loss due to illness was three training sessions. A moderate significant negative association was found between external training load and injury (r=-0.56; p=0.025). No associations were found between internal training load and injury; or between internal and external training load and illness respectively.

A significant relationship was found for external training load and injury incidence in weeks 5 to 8 for participants who ran less than 30km per week. A significant relationship was found for external training load and illness incidence in weeks 5 to 8, 9 to 12 and 13 to 16 for participants who ran less than 30km per week. A significant relationship was found between the ACWR of >1.5 and injury incidence in weeks 1 to 4, 5 to 8 and 13 to 16. A significant relationship was found between the ACWR of <0.5 and illness incidence in weeks 13 to 16.

Conclusion:

In conclusion a lower training load could potentially predispose to running-related injuries or the development of illness. Specifically, a weekly mileage of less than 30km per week may increase the risk of sustaining an injury or illness when training for an Ultramarathon event. An ACWR greater than 1.5 may increase the risk of injury in the subsequent week of training and an ACWR less than 0.5 may increase the risk of illness in the following week. Non-gradual changes to a weekly training load, whether increases or decreases, could increase the risk of incurring a running-related injury or illness. Maintaining an ACWR between 0.5 and 1.5 appears to be optimal in minimising the risk of sustaining a running-related injury or illness. We therefore recommend the use of both absolute and relative workloads in the monitoring of an athlete's training load with the aim of minimising injury and illness risk and maximising performance in ultramarathon runners.

CHAPTER 1: INTRODUCTION AND SCOPE OF THE DISSERTATION

1.1 Introduction

Endurance running has become increasingly popular over the past three decades due to its numerous health benefits and relative accessibility (Van Gent et al., 2007). In particular, there has been a significant rise in participation in ultramarathon running events in North America (Hoffman, 2016). Despite the positive benefits, endurance running has been associated with an increased risk of developing musculoskeletal injury (Krabak, Waite, & Lipman, 2013). This is evidenced by an overall running-related injury incidence rate ranging between 18% and 92% in ultramarathon runners (Lopes, Hespanhol, Yeung, & Pena Costa, 2012; Yamato et al., 2015). In addition to this association with injury, ultramarathon running seems to also influence illness risk. While consistent, moderate-intensity exercise has beneficial effects on general health and immune system function (Walsh et al., 2011), prolonged high-intensity exercise has been shown to impair immune system function and thus increase the risk of acquiring an upper respiratory tract infection (Gleeson, Bishop, Oliveira, & Tauler, 2013).

Therefore, the training load of endurance runners, could potentially have a profound effect on the development of both running-related injury and illness (Gabbett, 2016). Training is performed in order to bring about positive physiological adaptations in preparation for an athlete's sporting endeavour, with the aim of maximising performance. However, it is hypothesised that too great a training load could predispose an athlete to injury. In contrast, too small a training load could possibly lead to inadequate conditioning for the requirements of the sport, and thus result in injury and reduced performance (Gabbett, 2016). Therefore, finding the optimal training load to maximise performance, whilst minimising injury and illness risk, should be the goal of both coaches and athletes. Training load as defined by Gabbett (2016) is the combination of both the absolute load (internal and external training load) and the relative load (week to month ratio). The internal load of a training session can be calculated as duration multiplied by Rating of Perceived Exertion (RPE) (Coutts, Wallace, & Slattery, 2004; Lambert & Borresen, 2010) whilst the external training load refers to distance, duration, intensity and frequency (Borresen & Lambert, 2009).

The acute:chronic workload ratio (ACWR) describes the acute load in relation to the chronic load (Drew & Finch, 2016). The acute chronic workload ratio has been utilised as an outcome measure to monitor an athlete's training load over time (Hulin, Gabbett, Lawson, Caputi, & Sampson, 2015).

An ACWR of between 0.8 and 1.3 has been proposed to reduce injury risk in team sport athletes such as rugby, soccer and cricket. If an athlete's ACWR is outside of this proposed 'sweet spot', the risk of injury and illness is thought to increase. However, this relationship has not been adequately established in ultramarathon runners. Therefore, understanding the relationship between overtraining and undertraining in an ultramarathon running population may prove to be beneficial in terms of minimising the risk of injury and illness and maximising performance in these athletes (Gabbett & Whiteley, 2017).

Problem Statement: The epidemiology of running-related injuries and illness in ultramarathon runners is well documented in the literature. However, the relationship between injury, illness and training loads in ultramarathon runners specifically, is yet to be established. Recognising this relationship may help athletes and coaches in designing suitable training programmes that minimise the risk of injury and illness and maximise performance.

1.2 Aim and Objectives

1.2.1 Aim

The aim of this study was to determine the associations between both injury and illness incidences and training load parameters among ultramarathon runners in the 12-week period preceding an ultramarathon race and the four week period after the race.

1.2.2 Objectives

- To describe the incidence rate of overall and region-specific running-related injuries in a population of ultramarathon runners in the 16 week period surrounding an ultramarathon event.
- To describe the incidence rate of illness and illness-related symptoms in a population of ultramarathon runners in the 16 week period surrounding an ultramarathon event.
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- To describe the weekly and cumulative absolute training load parameters (internal load, external load) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.
- To describe the weekly relative training load parameters (ACWR) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.
- To determine whether there are any significant differences between the injured and uninjured groups and the ill and healthy groups with regard to: a) mean training parameters; b) mean internal training load; and c) mean external training load, over the 16 week period.
- To identify any significant associations between: a) absolute training load (internal training load; external training load) and injury incidence; and b) relative training load (ACWR) and injury and illness incidence over the 16 week period.

1.3 Significance of the study

Injury and illness incidences are high in ultramarathon runners (Lopes et al., 2012; Schwellnus et al., 2016). There may be a relationship between training loads, injury and illness. There has been limited research on the association between injury and illness incidence and training load parameters in ultramarathon runners. The aim of this study is to add to the current literature with regard to the injury and illness profiles of ultramarathon runners, but specifically in the three month period preceding and one month period following an ultramarathon event.

In addition, this study aims to establish any associations between injury or illness and training loads in ultramarathon runners in the four month period surrounding an ultramarathon event. This will improve knowledge of the contribution of training loads to injury and illness in this population and therefore hopefully guide training and injury prevention programs to minimise the risk of injury and illness, and optimise performance in ultramarathon runners.

1.4 Plan of Development

In this dissertation, a comprehensive review of the literature on ultramarathon running, running-related injuries and illness and the training injury prevention paradox will be presented (Chapter 2).

This is followed by a longitudinal, descriptive study to determine the association between training loads, injury and illness profiles in ultramarathon runners (Chapter 3).

The results, discussion and limitations of the dissertation will then be presented (Chapter 4 and 5 respectively), followed by a summary and conclusion chapter and recommendations for future research (Chapter 6).

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Running has become one of the most popular forms of exercise across the world over the past few years. This is partly due to its positive effects on physical fitness and general health (van der Worp et al., 2015) as well as its relative ease of access and low cost associated with running (Lopes et al., 2012). The primary disadvantage of running is the significantly higher risk of sustaining a musculoskeletal injury (Junior, Costa, & Lopes, 2013). Similarly, associations have also been found between running and an increased incidence of illness (Schwellnus et al., 2016).

Associations between training loads and injuries or illness have been identified in athletes. Therefore, training loads imposed on an athlete should be closely monitored as the response of an athlete to a load stimulus can be either positive (i.e. improved performance) or negative (i.e. injury and illness). Remaining injury and illness free is therefore of primary importance to all athletes and coaches (Drew & Finch, 2016).

The following section will provide an overview of ultramarathon running as a sport and examine current literature on the positive and negative effects of ultramarathon running. The review will then focus on running-related injuries and their associated extrinsic risk factors. Subsequently literature pertaining to illness epidemiology, the pathophysiological changes associated with the development of an illness and the influences of running competition on illness development will be discussed. Lastly, the review will provide an in-depth analysis of training load research and various established associations between training load, injury and illness. The review will conclude with a summary and critical appraisal of the literature.

Databases searched included PubMed, Medline, Cinahl, Africa Wide and Google Scholar. Keywords used in the search included: *'endurance running',' ultramarathons',' training load',' overtraining', 'volume', 'intensity', 'frequency', ' duration', 'running-related injuries',' training load and competition and injury', 'illness', 'training and illness', 'infection',* and *'immune and training and competition and performance'.*

2.2 Ultramarathon Running

In this section an overview of ultramarathon running will be given followed by the positive and negative effects associated with endurance running.

2.2.1 Introduction to ultramarathon running

An ultramarathon may be classified as *"a foot race longer than the standard 42.2 km marathon distance"* (Hoffman & Krishnan, 2013, p2939). An ultramarathon commonly involves distances ranging between 50 km and 160 km, with the 50 km ultramarathon being the most popular (Hoffman & Krishnan, 2013). According to Hoffman and Fogard (2011), the number of participants taking part and completing ultramarathon events has more than doubled from 1998 to 2008. More recent reports have indicated a mass of 17.1 million running participants across all running races in the year 2015 (Lee et al., 2017). As a result of this rise in popularity, the number of ultramarathon events has followed a similar rise during this period (Hoffman & Fogard, 2011). Ultramarathons tend to occur in more extreme conditions with regard to temperature, humidity and terrain in comparison to a standard marathon or half marathon (Krabak et al., 2013). Often ultramarathons need competitors to carry their own gear or equipment depending on the duration of the race. This includes clothes, shoes, nutrition and hydration (Krabak et al., 2013).

Despite the sudden rise in popularity of ultramarathons, very little is known about the type of participants who take part in these events (Hoffman & Fogard, 2011). According to Hoffman and Krishnan (2013), most ultramarathon participants are middle-aged males with a mean age of 36 years at the time of their first ultramarathon. A mean of seven years running experience before completion of a first ultramarathon event was also identified in this study.

In a review by Knechtle and Nickolaidis (2018), they compared both training and anthropometric characteristics of marathon and ultramarathon runners. It was found that in general, ultramarathon runners have successfully completed more marathons than marathon runners alone and at a faster pace. In terms of training, ultramarathon runners were found to run a greater distance per week and for more hours per week than marathon runners. With regard to anthropometric characteristics, ultramarathon runners had a lower body mass index which was also positively correlated with faster finishing times.

It is evident that the profile of an ultramarathon runner is somewhat different to that of a marathon runner. Despite this, ultramarathon runners are not exempt from a variety of challenges both in preparation for an ultramarathon event and on race day (Knechtle & Nikolaidis, 2018).

2.2.2 Positive and negative effects of ultramarathon running

Endurance running is known to have a beneficial effect on health, wellness and fitness (Van Gent et al., 2007). It has been shown to positively influence one's health and psychological well-being (Ryan, MacLean, & Taunton, 2006) as well as decrease the risk of developing chronic diseases of lifestyle and illnesses (Lee et al., 2017; Van Gent et al., 2007). These include coronary artery disease, cardiovascular disease, type-2 diabetes, osteoporosis, obesity, and certain types of cancer (Thompson et al., 2003). In a review conducted by Warburton, Nicol and Breden (2006) a significant reduction in cardiovascular and all-cause mortality was seen in individuals who were physically active. This is also supported by Lee et al. (2017) who found a 30% to 45% decrease in all-cause mortality. Physical inactivity has been associated with increased cardiovascular and cancer-related mortality as well as an increased risk of developing hypertension, hypercholesterolemia and obesity, specifically in women (Warburton, Nicol, & Breden, 2006).

Other benefits of regular physical activity include changes in the cardiovascular system like an increased aerobic capacity and changes in the musculoskeletal system including improved muscular strength and endurance (Thompson et al., 2003). The greater an individual's cardiorespiratory fitness, the greater the reduction in mortality. Exercise also has an anti-inflammatory effect which is beneficial in preventing the onset of chronic diseases of lifestyle (Walsh et al., 2011). Due to these health benefits and its relative accessibility, it is no wonder participation in running as a sport has increased greatly over the past thirty years (Lopes et al., 2012).

Despite the many benefits of running, there are also negative effects. Exercise-induced muscle damage, fatigue, increased risk of illness as well as a much greater risk of developing musculoskeletal injury are some of the established negative effects of endurance running (Saunders, Pyne, Telford, & Hawley, 2004). The eccentric lower limb loading components of endurance running have been associated with increased submaximal oxygen consumption, exercise-induced muscle damage and fatigue. This leads to the presence of delayed onset muscle soreness (DOMS) (Burgess & Lambert, 2010).

This is supported by Saunders et al. (2004) who found exercise-induced muscle damage and strength deficits associated with prolonged or intense exercise to be linked to increases in submaximal oxygen consumption. Exercise-induced muscle damage has also been linked to an increased perception of effort in endurance running (Marcora & Bosio, 2007). Evidence related to the cumulative effect of long-term endurance running on the musculoskeletal system and running performance requires further research.

Fatigue, defined as *"the decrease in pre-match/baseline psychological and physiological function of the athlete"* (Jones, Griffiths, & Mellalieu, 2017, p944), has been shown to lead to altered gait patterns and biomechanics, decreased running velocity, decreased running proficiency and therefore decreased performance (Jones et al., 2017). As the muscles become fatigued and require more effort to produce and maintain the same desired force, more oxygen is required (Lambert & Borresen, 2010). The relationship between fatigue and running economy has also been investigated. It is thought that prolonged periods of intense exercise lead to increased submaximal oxygen consumption and decreased running economy which ultimately affects an athlete's performance (Burgess and Lambert, 2010). Fatigue that is poorly managed has also been associated with an increased risk of developing the overtraining syndrome (Meeusen et al., 2013).

The overtraining syndrome (OTS) is another potential negative effect associated with prolonged exercise such as ultramarathon running (Meeusen et al., 2013). As athletes increase their training load with the intention of improving performance, they may experience acute periods of fatigue and decreased performance (Meeusen et al., 2013). If these periods of intensified training are accompanied by periods of sufficient recovery then positive adaptations to the training load may occur. This is called the 'supercompensation' effect (i.e. enhanced performance compared with baseline levels). The next training session can then be performed at a greater level or intensity (Meeusen et al., 2013). If these periods are not supplemented with sufficient rest and recovery, then maladaptation to the training load may occur (Jones et al., 2017). This results in stagnation and a decrease in performance which may last several weeks or months. According to Meeusen et al. (2013), 60% of female elite runners and 64% of male elite runners will experience at least one episode of the overtraining syndrome in their career. The lack of definitive diagnostic criteria in the diagnosis of the OTS makes this condition difficult to detect and treat (Meeusen et al., 2013).

According to Knechtle and Nikolaidis (2018), ultramarathon running can also affect various bodily organs such as the heart, liver and kidneys, the musculoskeletal system, the immune system as well as the hormonal system. When an athlete's body is placed under 'stress', such as during an ultramarathon, there is an 'acute-phase reaction' indicated by an increase in certain biomarkers.

These changes are normally transient depending on the duration and intensity of the workout (Knechtle & Nikolaidis, 2018).

With regard to the hormonal system, an ultramarathon has shown to lead to increases in cortisol levels, catecholamines and the growth hormone whilst a decrease in testosterone levels has been found. Of note from this study were the high levels of cortisol associated with increased pace in runners (Knechtle & Nikolaidis, 2018). The long-term reduction of testosterone levels in males has been related to decreased levels of libido and therefore decreased motivational behaviour. This can negatively affect one's performance (Knechtle & Nikolaidis, 2018). On the contrary, increased levels of estradiol were found in females. An increase in the above stress hormones increases the physical stress experienced by the body which can become chronic if not closely monitored. This highlights the importance of continuous monitoring in athletes (Knechtle & Nikolaidis, 2018).

Whilst the associations between endurance running and aspects of physiological function have been investigated, the most conclusive research in this regard pertains to the influence of endurance running on illness and injury development. The relationship between endurance running and running-related injuries has been extensively researched. The next section will therefore discuss the epidemiology of running-related injuries and the associated extrinsic risk factors.

2.3 Endurance running and running-related injury

In this section, the definition of what constitutes a running related injury will be discussed, followed by the epidemiology of running-related injuries and the associated risk factors.

2.3.1 Definition of running-related injuries

According to Kluitenberg et al. (2015) definitions of running-related injuries have been divided into three main categories, namely; 'all complaints'; 'medical attention incidents'; and 'time-loss injuries'. While the 'time-loss' injury definition is the most commonly used, the lack of consistency in the definition of what constitutes 'time-loss' may account for the large range of injury incidence reports in the literature (Kluitenberg et al., 2016). As running injuries are often of an overuse nature, develop slowly and re-occur, the 'time-loss' definition may be problematic in identifying a running-related injury. This is due to the fact that many runners continue to exercise despite having pain by adapting their training load accordingly. This allows them to continue running in the presence of musculoskeletal damage or irritation, and would therefore potentially lead to the under-reporting of injury incidence (Kluitenberg et al., 2016). Similarly, 'the medical attention incidents' definition of injury, which requires access to medical support, could also lead to the under-reporting of running-related injury incidence as not all runners will seek medical attention for their conditions. In contrast, the 'all complaints' injury definition could lead to over-reporting of running-related injuries as this definition includes all complaints recorded during sport regardless of their consequence (Kluitenberg et al., 2016). Due to this lack of consistency in injury reporting, it became clear that a consensus was required.

In the 2015 consensus statement, A Modified Delphi Approach' by Yamato et al., running-related injury was defined as: '*Running-related (training or competition) musculoskeletal pain in the lower limbs that causes a restriction on or stoppage of running (distance, speed, duration, or training) for at least seven days or three consecutive scheduled training sessions, or that requires the runner to consult a physician or other health professional'* (Yamato et al., 2015, p377). This definition is at least more specific in that it identifies a restriction on an athlete's training schedule which can therefore account for adaptations in their training load. It also accounts for consultations with a healthcare professional which may help in identifying more running-related injuries (Yamato et al., 2015). We have therefore chosen to use this definition of a running-related injury in our study.

2.3.2 Epidemiology of running-related injuries

As outlined in above sections, endurance running has numerous health benefits. However, the primary negative health effect of endurance running is the significantly increased risk of sustaining a musculoskeletal injury (Hespanhol Junior et al., 2013). Lopes et al. (2012), reported running-related injury incidences ranging from 18% to 92%. Other studies have reported similarly high incidences of running-related injury (Yamato, Saragiotto & Lopes, 2015; Buist et al., 2010). These wide incidence ranges can be accounted for due to the various definitions of running-related injuries as well as the different characteristics of participants that have been studied (Lopes et al., 2012). Other factors that may influence injury incidence outcomes include the type of study design used and the manner in which a running-related injury is assessed (Kluitenberg et al., 2016).

Running-related injuries are predominantly overuse in nature. This is evidenced by 80% of all running-related injuries being classified as overuse, rather than acute (van der Worp et al., 2015). Overuse injuries can be defined as: "*any injury with a gradual onset, which influenced performance during competition or training*" (Knobloch et al., 2008, p673). As ligaments, tendons and cartilage adapt more slowly to increased loads, these structures are at greater risk of sustaining an injury in comparison to muscles (van der Worp et al., 2015). Using the consensus statement definition of running-related injuries which comprises three or more missed training sessions, overuse injuries can be identified. These would otherwise be missed if training sessions were reviewed individually as athletes are often able to adapt their training load due to pain without stopping running (Bas Kluitenberg et al., 2016).

Running-related injuries have been shown to predominantly occur in the knee and lower leg (Van Middelkoop, Kolkman, Van Ochten, Bierma-Zeinstra, & Koes, 2007), with the knee being reported as the most commonly injured anatomical region in endurance runners (Lopes et al., 2012; Hoffman & Krishnan, 2014). Common pathologies affecting these regions in endurance runners include patellofemoral pain syndrome, iliotibial band friction syndrome, patella tendinopathy, medial tibial stress syndrome, plantar fasciitis and Achilles tendinopathy (Taunton et al, 2002; Knobloch et al, 2008; Fredericson & Misra, 2007). Running-related injuries of the hip, pelvis and lower back are less common (Taunton et al., 2002).

The high incidence of running-related injuries implies the presence of inherent risk factors associated with participation in endurance running (van der Worp et al., 2015). Identifying these risk factors would assist in the understanding of the aetiology of running-related injuries, and aid in the management and prevention of these common conditions.

Due to the importance of identifying these risk factors, extensive research has been undertaken in this regard. The next section will review risk factors associated with increased injury incidence in ultramarathon runners.

2.3.3 Modifiable extrinsic risk factors for sustaining a running-related injury

Due to the relatively high incidence of running-related injuries, the potential intrinsic and extrinsic risk factors that may predispose an athlete to injury must be considered (Van Middelkoop, Kolkman, Van Ochten, Bierma-Zeinstra, & Koes, 2008). Running-related injuries are often the result of a complex interaction between the two. Intrinsic risk factors include age, sex, Body Mass Index (BMI) and features of anatomical alignment (Buist et al., 2010; Kluitenberg et al., 2015). Extrinsic risk factors include but are not limited to training, running experience, shoes, running surface and previous injury history (van der Worp et al., 2015). Modifiable risk factors include those which can be changed by undertaking certain measures. Modifiable risk factors are important for healthcare professionals and athletes as they can be addressed with the aim of preventing the onset of various running-related injuries.

There is contradictory evidence for age as a predisposing factor to injury (Hoffman & Krishnan, 2014), or as a protective factor against injury (Van Gent et al., 2007). Limited research exists thus far showing the effects of age on running-related injuries. Only one study conducted by Wen et al. (1998), as cited in van der Worp et al. (2015), found that a lower age serves as a protective factor against injury and that increased age may be significantly associated with certain running-related injuries namely; hamstring strains and Achilles tendinopathies (van der Worp et al., 2015). As age is a non-modifiable risk factor, we have chosen to not discuss this further.

A potential risk factor for injury is running experience (Buist et al., 2010; Hespanhol Junior et al., 2013). According to van der Worp et al. (2015), five high quality studies reported little evidence that more running experience serves as a risk factor for injury and that less running experience (i.e. less than a year) serves as a protective factor against running-related injuries. A higher incidence of running-related injuries was found in novice runners per 1000 hours run in comparison to experienced runners. Junior, Costa and Lopes (2013) found that less than three years of running experience increased the risk of injury. This is also supported by Kluitenberg et al., (2015).

In a study conducted by Reinking, Austin and Hayes (2013) which examined exercise-associated leg pain, less than three years running experience and a lower training mileage was also found to increase the risk of injury. Therefore, the more running experience one has the lesser the risk of injury (Nielsen, Buist, Sørensen, Lind, & Rasmussen, 2012).

A previous history of running-related injury and an increase in mileage are significant risk factors for determining future injury (Van Middelkoop et al., 2008). Saragiotto et al. (2014) found a previous history of injury in the past 12 months to be a significant risk factor for future injury. Previous injuries are strongly associated with sustaining another running-related injury often due to inadequate or incomplete rehabilitation (Molloy, 2016). The resultant effects are muscle imbalances, biomechanical discrepancies and gait abnormalities. This alteration in biomechanics is often thought to be a protective strategy seen in individuals. However, instead of preventing injury it often causes other musculoskeletal problems (Saragiotto, Hespanhol Junior, Rainbow, Davis, & Lopes, 2014).

Time off from running also leads to decreased aerobic fitness and decreased muscle strength and endurance, which further increases the risk of re-injury (Molloy, 2016). While an increase in running mileage has been proposed to cause patellofemoral pain and patella tendinopathies, a greater weekly mileage has also been suggested to serve as a protective factor against injury (Molloy, 2016). It is thought that runners who have a greater cumulative weekly mileage have a relatively higher threshold for injury (Molloy, 2016). This will be discussed further in section 2.3.4. An increase in running mileage increases the stress (number of repetitions) applied to the muscles, tendons and joints (Hreljac & Ferber, 2006). If this increased stress is above the physiological limit of that structure then an injury will occur. If this stress is below the physiological threshold then positive adaptations will occur (Hreljac & Ferber, 2006). It is evident that more research is needed to clarify this contradictory information.

While fatigue has not been found to be a strong external risk factor for injury, one cannot overlook its effects. As running-related injuries are overuse injuries by nature, this repetitive loading ultimately leads to fatigue which increases the risk of injury (van der Worp et al., 2015). Fatigue decreases the muscles ability to absorb load thereby increasing the strain across the muscles, bones and joints (Molloy, 2016). A tibial stress fracture, another common type of injury in runners, is a good example of repetitive loading leading to muscular fatigue of the tibialis anterior muscle. The resultant imbalance between ankle dorsi- and plantarflexor muscles increases the impact on the tibial bone increasing the risk of injury (Molloy, 2016).

Following competition, decrements in performance are commonly seen (Jones et al., 2017). This may include decreased muscle power due to muscle damage, impaired immune system function, decreased mood state and altered neuromuscular function. This state of fatigue can take the body a few days to recover. Accumulation of such a fatigued state can further affect an athlete's performance. Therefore, finding the balance between when to prescribe load and when to prescribe rest or recovery is of paramount importance (Jones et al., 2017).

2.3.4 Training load as an extrinsic risk factor for running-related injury

Training load is the combination of both internal and external training loads (absolute load) as well as the acute:chronic workload ratio (relative load). Workload is *"the cumulative amount of stress placed on an individual from multiple training sessions and games over a period of time"* (Windt & Gabbett, 2017). Training loads that are too high or too low have been associated with an increased risk of injury (Gabbett, 2016). The following section will define the various aspects of training load and how they pertain to injury.

2.3.4.1 Internal training loads

Internal training load can be quantified as the Rating of Perceived Exertion (RPE) times the duration of the training session (Coutts et al., 2004; Lambert & Borresen, 2010). The rating of perceived exertion is an athlete's subjective description of 'how hard' the workout was according to a 10-point scale known as the modified Borg scale (Borg, 1982). Thirty minutes post-exercise the athlete rates how difficult the workout was with 1 representing very easy and 10 representing maximum (Herman, Foster, Maher, Mikat, & Porcari, 2006). It reflects the physiological and psychological stress placed on the athlete at the time of the session (Lambert & Borresen, 2010).

The RPE scale has been found to be reliable during repeated measures of the same exercise bout. It has also been accepted as an objective measure of exercise intensity and has therefore been deemed valid in terms of monitoring exercise load and training intensity (Herman et al., 2006). This simple yet effective method of measuring the dose or intensity of the training load in endurance sports helps to determine the relationship between internal training load and performance (Coutts et al., 2004; Foster et al., 2001).

This enables coaches and athletes to monitor their proposed internal training loads and allow for appropriate periodisation of the training regimen (Foster et al., 2001).The internal load and therefore physiological stress experienced by the athlete is a result of the external load applied to the athlete (Bourdon et al., 2017).

The internal load can be measured using other variables such as heart rate, heart rate recovery and lactate accumulation. Heart rate tracking is a common method used to measure the intensity of the exercise bout (Borresen & Lambert, 2009). As the intensity of the exercise session increases so too does the heart rate of the athlete. This shows a linear relationship between steady-state workload and heart rate. While various factors such as environmental conditions and the training and hydration status of the athlete can affect the internal load experienced, if these variables are controlled for then the accuracy of this method of measurement improves (Borresen & Lambert, 2009).

Lactate accumulation is both difficult to measure as well as highly variable amongst each individual. The mode of exercise testing, diet and the state of fatigue of the athlete can all affect the lactate concentration. This decreases the validity of using lactate concentration as a measure of exercise intensity and therefore the internal load placed on the athlete (Borresen & Lambert, 2009).

Training induces physiological adaptations in performance. These may be positive or negative changes (Lambert & Borresen, 2010). High training loads over prolonged periods of time can lead to overtraining which increases the athlete’s risk of injury (Gabbett, 2016). Even small increments in training load can have a noticeable increase on injury risk. This applies to changes in the week-to-week training load as well as the overall training load over a period of time. Bearing in mind that every training session can potentially lead to injury, in a systematics review by Nielsen et al (2012) it has been found that a five to ten percent increase in the weekly training load for runners is best. This is to help minimize the risk of injury and optimise improvements in training and performance (Gabbett, 2016).

2.3.4.2 External training loads

The external training load refers to the load imposed on the athlete, and includes volume, duration, intensity and frequency of exercise (Borresen & Lambert, 2009). These are also known as training characteristics. Evidence suggests that running-related injuries, which are primarily overuse in nature, are more than likely the result of training errors (i.e. changes in the above-mentioned training characteristics either individually or in combination with each other) (Nielsen et al., 2012). Volume refers to the cumulative weekly mileage run measured in miles or kilometres; duration refers to the amount of hours or minutes per week spent running; intensity refers to the average pace per run or average sessional RPE; and frequency refers to the number of training sessions/runs completed per week (Nielsen et al., 2012).

To date there is varying literature with reference to the relationship between training volume and running-related injuries (Nielsen et al., 2012). One study found that there is an increased risk of injury when running more than 20 miles (32 km) per week, whereas two studies found a greater risk of sustaining a running-related injury if runners ran more than 40 miles (64 km) per week (Nielsen et al., 2012). Another study found a positive association between distance covered in a month and subsequent risk of injury in the following month (Nielsen et al., 2012). When comparing injured runners to uninjured runners, injured runners had run more miles per week. A possible relationship between training volume (i.e. miles run per week) and the type of running-related injury sustained has also been proposed. However, this needs more research as current literature is contradictory (Nielsen, Nohr, Rasmussen, & Sorensen, 2013).

Whilst an increased incidence of running-related injury per 1000 hours run per week has been identified, there is no association between the likelihood of injury and increasing the weekly duration of running (Nielsen et al., 2012). It would therefore seem more plausible to relate injury risk to exposure time as literature shows that as a runner's weekly mileage increases, their number of injuries decrease (Nielsen et al., 2012). It is possible that this decreased injury risk with an increase in mileage is due to maturation or experience of the runner. Experienced runners have a higher injury threshold. It is this increased injury threshold that is associated with a greater weekly mileage (Nielsen et al., 2012). This would imply that a higher chronic workload is in fact protective of injury (Windt & Gabbett, 2017).

Increasing the intensity of an exercise bout is associated with an increased risk of injury (Gabbett, 2016). It has been found that a quicker running pace may increase the risk of sustaining certain running-related injuries in comparison to others. These include, but are not limited to, iliotibial band friction syndrome and Achilles tendinopathy (Nielsen et al., 2013). Schwellnus, Allie, Derman and Collin (2011) observed the effect of increased running pace and exercise-associated muscle cramps in runners competing in a 56 km ultramarathon event. Greater speed and exercise-associated muscle cramps were found to be positively correlated (Schwellnus, Allie, Derman, & Collins, 2011).

Increasing the frequency of training also increases the risk of injury (Nielsen et al., 2012). Nielson, Buist, Sorensond, Lind and Rasmussen (2012) found a frequency of six to seven runs per week greatly increases the risk of injury. Molloy (2016) found that a frequency of more than three runs per week is associated with an increased risk of injury. However, a very low frequency of running may also increase the risk of injury as the athlete is not conditioned enough or adequately prepared for the demands of their respective sport (Gabbett, 2016). Therefore, a middle ground of two to five runs per week might be most fitting in terms of decreasing the risk of injury and maximising performance (Nielsen et al., 2012).

In a study conducted by Warden, David and Fredericson (2014), both increased running speed and increased frequency of running were associated with an increased risk of injury, specifically bone stress injuries. Increased running pace was associated with higher ground reaction forces on the bone and an increase in the frequency of training was associated with an overall increase in the amount of loading through the bone. If not compensated for with sufficient rest, this altered loading regime can lead to micro-damage of the bone and eventually result in bone stress injuries (Warden, Davis, & Fredericson, 2014).

It is important to recognise the influence of training volume on sustaining a running-related injury. If an athlete's training volume is monitored and controlled then frequency becomes less important in preventing an injury (Nielsen et al., 2012). Therefore, one cannot examine the above training parameters independently as each directly or indirectly influences the other. Continued research is needed in this field to determine what the optimal training parameters are, in order to minimize the risk of sustaining a running-related injury and maximise performance. The next section will discuss the impact of absolute and relative workloads imposed on the athlete.

2.3.4.3 Absolute and relative workloads

Monitoring of training loads has proven to be beneficial to determine if an athlete is positively adapting to the prescribed training loads (Bourdon et al., 2017). This is done in combination with assessing for fatigue so as to minimise the risk of overtraining, injury and illness (Bourdon et al., 2017). Absolute and relative workloads have also been proposed to express and monitor the load placed on an athlete (Drew & Finch, 2016). The 'absolute' load refers to the resultant load (both internal and external load) placed on an athlete over the period of a day or week.

The ’relative’ load describes the percentage increase in load over a week or even month or the ratio between the acute load (week) and chronic load (month) (Drew & Finch, 2016).

This is helpful as it reflects what is now known as the ‘acute:chronic workload ratio’ (ACWR) (Gabbett, 2016). This allows athletes of different capabilities to be compared to their own training load which can then be used as a measure of relative risk of injury in the following week (Drew & Finch, 2016). It is suggested that internal and external workloads should be monitored in conjunction with one another to provide greater feedback with regard to how the athlete is coping with the imposed stress of training (Bourdon et al., 2017). The ACWR will be discussed in more detail in Section 2.5.1 of the literature review (p32).

For example, the same external load (i.e. distance and speed) placed on an athlete on a given day could produce different internal loads (i.e. rating of perceived exertion) on another day. This could be due to psychological stressors, muscle fatigue, insufficient sleep and recovery, poor nutrition and hydration or the presence of illness-related symptoms. Therefore, the combination of the two loads helps the athlete and coach assess how ‘ready’ or ‘fresh’ the athlete is for subsequent training sessions (Bourdon et al., 2017).

Current literature regarding training load and injury is extensive however, there is still much that we do not know. With reference to exercise and illness, literature is minimal and somewhat controversial. More information is needed to explore the relationship between endurance running and illness specifically. The following section will therefore discuss the epidemiology of illness in endurance runners.

2.4 Endurance running and illness

There is little evidence around the epidemiology of illness in athletes and endurance runners. Section 2.4 will review the most common illness-related symptoms in endurance runners as well as the effect of endurance running on the immune system. Subsequently, the pathophysiological changes associated with illness will be reviewed followed by literature with regard to competition and illness specifically.

2.4.1 Epidemiology of illness

The International Olympic Committee consensus statement on load in sport and risk of illness defined illness as: "*a new or recurring illness incurred during competition or training receiving medical attention, regardless of the consequences with respect to absence from competition or training*" (Schwellnus et al., 2016, p1044). According to the literature, the incidence proportion of acute illnesses in competitive athletes taking part in international competitions is 6% to 17% (Schwellnus et al., 2016). A higher proportion of acute illnesses has been found in female athletes especially during the winter sports (Schwellnus et al., 2016). According to Krabak, Waite and Schiff (2011), 95% of injuries or illnesses in multi-day ultramarathon events are minor in severity with medical illnesses only accounting for 7.5%. Illness is associated with decreased performance, missed training sessions and termination of competitions (Schwellnus et al., 2016).

Allergies and exercise-induced asthma are common running-related illnesses in ultramarathon runners, with prevalence rates of 25% and 13% respectively (Hoffman & Krishnan, 2014). The most common biological system affected is the respiratory system accounting for approximately 50% of acute illnesses (Schwellnus et al., 2016). Upper respiratory tract infections (URTIs) are seen in endurance athletes pre- and post-race (Van Tonder et al., 2016). Moderate intensity levels of exercise have shown to enhance immune system function in comparison to a sedentary lifestyle. Still, higher training loads are associated with an increased incidence of upper respiratory tract infections and an elevated pro-inflammatory cytokine response to antigens (Gleeson et al., 2013). There is currently inconclusive evidence regarding the exact cause of upper respiratory tract infections. It is not clear whether these infections are due to inflammatory stimuli associated with prolonged periods of intense training or whether they are due to viral or bacterial infections (Walsh et al., 2011).

Medical illnesses such as exercise-associated collapse secondary to heat-related illness and exercise associated hyponatremia (EAH) are also common in marathon runners (Krabak, Waite, & Lipman, 2014). Heat-related illness is the result of the body's inability to regulate the core body temperature (Krabak et al., 2013). This could be due to a variety of factors such as low levels of fitness, poor acclimatization, comorbidities, the use of certain medication, external factors such as humidity, the duration or intensity of exercise and hypo- or hyper hydration (Krabak et al., 2013). Exercise associated hyponatremia is a low concentration of sodium that occurs in response to a combination of factors associated with prolonged endurance exercise (Krabak et al., 2013). It is thought to be due to over-hydration with the resultant depletion of sodium. As this is a potentially life-threatening condition if not treated correctly, the recognition and correct management of symptoms is extremely important (Krabak et al., 2013).

Hydration is vital in terms of successfully completing an ultramarathon event. Despite this, many athletes are uneducated with regard to how much fluid to consume and therefore overhydrate resulting in sodium losses (i.e. hyponatremia) as mentioned above (Krabak et al., 2014). Dehydration is also associated with the stress hormones adrenalin and cortisol, therefore fluid intake during exercise not only helps attenuate dehydration but it also helps to decrease the level of circulating stress hormones which are thought to have an effect on immune system regulation and function (Gleeson et al., 2004).

While dehydration is not an illness per se, the effect of dehydration on the immune system may increase the risk of sustaining an illness. Fluid intake helps to maintain saliva production within the mouth which has antimicrobial properties and is therefore protective against infections to some extent (Gleeson et al., 2004). Current literature advocates drinking to thirst to optimise exercise performance and reduce the risk of fluid overload (Noakes, Hew-butler, & Tucker, 2007). Endurance running has been found to affect the immune system in various ways. The next section will therefore analyse the physiological changes associated with the development of illness.

2.4.2 Physiological changes associated with the development of illness

The body is subjected to various stressors (musculoskeletal, oxidative and systemic) following bouts of endurance exercise (Nieman, 2009). This leads to several changes in both the innate immune system and the acquired immune system often causing a period of decreased immunity which increases the athlete's risk of infection (Nieman, 2009; Walsh et al., 2011). It is thought that production of secretory immunoglobulin A (IgA) serves as the first line of defence against pathogens in the immune system (Walsh et al., 2011).

The transfer of IgA into the saliva provides defence against microbial pathogens penetrating the mucosal epithelium and neutralises viruses within the epithelial cells (Walsh et al., 2011). Associations between low levels of saliva IgA and an increased incidence of URTIs have been found (Nieman, 2009; Walsh et al., 2011). Therefore, while moderate levels of exercise may increase levels of secretory IgA and thus decrease the risk of developing URTIs, prolonged (more than ninety minutes), intense exercise is associated with reduced levels of IgA. As a result, the risk of developing an URTI during periods of high intensity training is increased (Walsh et al., 2011).

The acquired immune system is designed to fight infections. It is composed of T helper lymphocytes that can be subdivided into two groups: type 1 (Th1) and type 2 (Th2) lymphocytes. The Th1 cells mainly protect against intracellular pathogens such as viruses; whereas Th2 cells protect against extracellular parasites as well as stimulate the production of antibodies (Walsh et al., 2011). The Th2 cells can activate B lymphocytes which in turn proliferate and differentiate into memory cells and plasma cells. Plasma cells are responsible for secretory immunoglobulin A as mentioned above (Walsh et al., 2011). Increased training loads have been found to lead to a decrease in Th1 cells and therefore reduced T cell proliferation, and a reduction in B cells which results in a decline in Ig synthesis (Walsh et al., 2011).

This cascade leads to depression of the acquired immune system and is thought to be related to increased levels of circulating stress hormones and an imbalance between pro- and anti-inflammatory cytokines (Walsh et al., 2011). The two hormones that have been found to be elevated in the blood following periods of prolonged, intense exercise include adrenalin and cortisol (Gleeson, Nieman, & Pedersen, 2004). While this depression may be transient following an acute bout of exercise, if there is insufficient recovery between exercise sessions, then this depression of the acquired immune system may become chronic. This commonly occurs in athletes preparing for an upcoming event or competition where there is a mismatch between training and recovery (Walsh et al., 2011).

The effect of illness on athletes is missed training sessions, decreased performance and impaired organ system function, which can still be affected up to four days post recovery (Schwellnus et al., 2016). An imbalance between psychological stress and recovery has also been related to illness. This can have a profound effect on the mental psyche of an athlete especially if close to a competition or event (Schwellnus et al., 2016).

2.4.3 Competition and illness

Other risk factors associated with acute illnesses in athletes include psychological stressors (inside and outside of the sport), international travel and high competition loads (Schwellnus et al., 2016). Competition load can refer to either a single event or multiple events. Competition itself is associated with an increased risk of illness, particularly in the first two weeks following an event (Van Tonder et al., 2016). Research thus far shows that athletes are susceptible to illnesses in the pre-competition, competition and post-competition period. As endurance runners train for months in preparation for an event, their risk of sustaining an illness is constantly elevated. Post-race upper respiratory tract infections are associated with increased exercise intensity (i.e. faster runners) as well as pre-race upper respiratory tract symptoms (Schwellnus et al., 2016). The physiological stress imposed on the athlete's body (during and post-race) takes longer to subside due to the increased time spent running to complete an endurance event. The long term effects of endurance running on an athlete's health and wellness are not known (Nieman, 2009).

It is evident that there is a relationship between training for endurance events, performance and participation in endurance events and the development of illness. Endurance athletes generally endure high training volumes to ensure sufficient preparation and ultimately success for an endurance event (Walsh et al., 2011). However, as discussed above, immune dysfunction is most commonly seen after prolonged, moderate to high intensity exercise with inadequate hydration (Walsh et al., 2011). A prolonged, moderate to high intensity training session is classified as more than 90 minutes of exercise at 55% to 75% of an athlete's VO_2max. Foster (1998) and Gleeson, Nieman and Pederson (2003), both found a sudden spike in training load and competition to be a risk factor for illness. However, Fricker et al (2005), found no relationship between weekly training mileage, weekly training and illness incidence.

2.4.3.1 Training and illness

In a study investigating the impact of training on illness incidence, significant differences in training parameters were found between those who sustained an URTI and those who did not (Fricker et al., 2005). Interestingly, those that remained healthy reported a greater weekly running mileage in comparison to those who experienced symptoms of illness. However, whilst a higher volume of training was associated with illness development, a higher training intensity was identified in the illness group in comparison to the healthy group. Following an episode of an URTI, training and performance were not affected. Overall, the 'healthy' group reported a slightly greater training load than the 'unhealthy' group of runners (Fricker et al., 2005).

An imbalance between training and recovery also contributes to illness (Walsh et al., 2011). According to the consensus statement by Walsh et al (2011), advice for endurance athletes would be to gradually increase their training loads in a periodised manner, prevent monotony by adding variety to the exercise routine and avoid excessive stress with recurrent hard training sessions. Increasing the frequency of shorter duration training sessions, maintaining the intensity of training and decreasing the volume of training is advisable. Long, high intensity training sessions should also be avoided when athletes show signs or symptoms of an URTI (Walsh & Oliver, 2015). Adequate recovery is important and should be implemented following competition or high intensity/exhaustive exercise. Two to three moderate-to-easy sessions following a hard session according to the RPE scale is recommended (Walsh & Oliver, 2015). A recovery week every third week (i.e. shorter macrocycles) can also help prevent the onset of illness by preventing overreaching or excessive training (Walsh & Oliver, 2015).

As athletes prepare for an ultramarathon and begin to increase their training load, it is important to consider all factors that could affect an athlete's response to loading (Coutts et al., 2004). Previous research models have only reviewed the effect of intrinsic and extrinsic risk factors that may predispose an athlete to injury coupled with exposure to an inciting event. More recent research now accounts for the possibility that sports participation may not actually lead to an injury or illness but rather subsequent positive physiological adaptations following a stressful event. These adaptations result in a greater injury and illness threshold (Windt & Gabbett, 2017). The following section will address the proposed training load paradox and the use of the acute chronic workload ratio in monitoring an athlete's training load.

2.5 Training load paradox

Despite the changes in research models such as the performance model suggested by Banister et al (1975), the effects of absolute and relative workloads placed on the athlete are often not considered in training programmes. Workload, as defined by Gabbett et al. (2014), is *"the cumulative amount of stress placed on an individual from multiple training sessions and games over a period of time"* (Windt & Gabbett, 2017, p2). The idea is to prescribe such training loads so as to induce positive physiological adaptations on the athlete such as an improvement in fitness, performance and skill development. This should be implemented without overloading the athlete, which would otherwise cause negative effects such as injury, illness, fatigue or delayed onset muscle soreness (Saunders et al., 2004). Exercise parameters such as distance, duration, intensity and frequency all influence the athletes physiological response to the given training load. Ultimately this will have an impact on future performance (Borresen & Lambert, 2009). To minimise the risk of injury and illness and maximise performance an understanding of the effect of these training parameters on the athlete is of paramount importance (Borresen & Lambert, 2009).

The benefit of combining acute and chronic workloads (relative workloads) in the monitoring of the training-injury prevention relationship will be discussed in the next section.

2.5.1 Acute to chronic workload ratio

The acute:chronic workload ratio describes the cumulative weekly load (acute) in relation to the cumulative monthly (chronic) load (Drew & Finch, 2016). 'Acute' is one week in duration and 'chronic' can be three to six weeks in duration (Gabbett, 2016). This is to allow for the accumulation of load in order to fully understand the relationship between training load and injury. Four week cycles are most commonly used according to periodisation in training, (Bowen, Gross, Gimpel, & Li, 2017). Acute loading is comparable to a state of fatigue and chronic loading is comparable to a state of fitness. Therefore, the ratio tells us how 'prepared' the athlete is and their relative risk of injury.

It is proposed that if the acute load is too high in proportion to the chronic training load, then the risk of injury increases. If the acute load is too low, then training adaptations do not occur and this too can pose as a risk factor for injury. A very high acute:chronic workload ratio has been found to increase the risk of injury in the current week of training in sports such as cricket and rugby as well as the subsequent one to two weeks of training (Hulin et al., 2015).

According to Jones, Griffiths and Mallelieu (2017), 40% of injuries can be predicted if there had been more than a 10% increase in the acute (weekly) load. However, a higher chronic workload overall may be protective against injury in combination with a moderate or moderate to high workload ratio (Jones et al., 2017).

Examination of the 'acute' workload in relation to fatigue and the 'chronic' workload in relation to fitness shows that training at moderate 'acute:chronic workloads' combined with a high chronic workload overall, may decrease the risk of injury (Hulin et al., 2015). Thus, a higher chronic workload increases the athlete's injury threshold. If athletes can safely train through these periods of high workloads then they may become more resilient to injury. Higher chronic loads may in turn serve as a protective factor against injury (Bowen et al., 2017; Gabbett, 2016). A sudden, drastic increase in training loads (a spike in the acute workload), is likely to increase the risk of injury and therefore should be closely monitored. This highlights the multifactorial nature of training loads and injury. Therefore, establishing a balance between training, competition and recovery is essential (Bowen et al., 2017).

The optimal training load is of utmost interest to athletes and coaches but is yet to be determined (Bourdon et al., 2017). Research has shown that training loads may be described as 'the vehicle that drives athletes towards or away from injury' (Bourdon et al., 2017). Loading enhances the body's ability to tolerate load as well as develop sport specific physical traits that are needed to meet the demands of the respective sport and reduce the risk of injury (Bourdon et al., 2017).

Walter et al. (1989) and Macera et al. (1989), as cited in Rasmussen, Nielsen, Juul & Rasmussen (2013), proposed that a training volume above $64 km.wk^{-1}$ seemed to be a 'tipping point' for running-related injuries (Rasmussen, Nielsen, Juul, & Rasmussen, 2013). Their recommendation was that athletes should reduce their weekly mileage to below this level to minimise the risk of injury. It has been advised that athletes should only increase their weekly training load by five to ten percent per week in order to minimise the risk of injury (Gabbett, 2016). Different body tissues (such as muscles and tendons) respond at different rates of loading. The time taken for tendons and muscles to adapt and remodel varies according to the type of activity and the load applied. This should be taken into account when formulating a training programme (Gabbett & Whiteley, 2017).

While the acute:chronic workload ratio provides information regarding the athlete's response to training, this method appears to be limited in terms of predicting future performance (Bourdon et al., 2017).The acute:chronic workload ratio referred to above, only accounts for distance or duration of loading and does not consider the intensity of loading (Jones et al., 2017).

An increased overall external intensity (i.e. running speed) and an increased internal intensity (i.e. rate of perceived exertion) may increase the risk of injury as opposed to protecting the athlete from injury. This is due to the increased stress placed on the athlete's body. A lower training intensity may serve as a form of recovery allowing positive adaptations to occur. This may prove to be beneficial for an athlete (Jones et al., 2017).

Recently, Lolli et al. (2017) criticised the use of the ACWR. They found that including the acute load in the chronic load calculation of the ACWR resulted in 'mathematical coupling'. This means that one variable may contain components of the second variable which can lead to an association between variables that may not otherwise exist. This is called a spurious correlation.

Carey et al. (2018) also criticised the use of discretization in the studies of training loads using the ACWR and predicting future injury risk. Discretization breaks down data into categories and uses a reference category to compare each other category to it to determine if there is a significant result. The problem with the use of categories is that each individual within that category is assumed to have equal risk whether they are at the top end or bottom end of that category (Carey et al., 2018). The study concluded that discrete models are inaccurate when estimating the relative risk between training loads and injuries and that continuous models should rather be used. This is partly due to that fact that minimal literature exists thus far in terms of defining what the appropriate reference category should be so as to limit the risk of false findings (Carey et al., 2018).

William, West, Cross and Stokes (2017), have also censured the acute:chronic workload ratio due to its inability to account for changes in fitness and fatigue over time. They have proposed that it does not account for variations in load or consider the means in which load is accumulated (Williams, West, Cross, & Stokes, 2017). Thus the authors have proposed the use of exponentially-weighted moving averages (EWMA) in the calculation of the ACWR as it focuses less on older values and gives more weighting to current training loads towards the end of the four week cycle. This is when fatigue is thought to accumulate. One and four week cycles have been chosen due to current literature related to periodization in sport and training (Williams et al., 2017).

As the EWMA places more emphasis on training loads accumulated towards the end of the four week period it may serve as a better method of predicting fatigue. This may help in the management of an athlete's training load in comparison to the current rolling averages (Williams et al., 2017). Rolling averages have resulted in different end ratios in comparison to EWMA ratios. This could impact whether an athlete is thought to be in the 'safe zone' or at risk of injury in the following week.

The EWMA therefore appears to be more sensitive in determining spikes in loading in comparison to rolling averages and thus is recommended in the monitoring of an athlete's training load. However, literature is still scarce in this method of monitoring and so more research is needed (Williams et al., 2017) (Table 1).

Table 1: The different methods of calculation of the Exponentially Weighted Moving Average and the Acute:Chronic Workload Ratio (Gabbett, 2016; Williams et al., 2017)**.**

	EWMA	**ACWR (RA)**
Method of calculation	$EWMA_{today}=Load_{today}*\lambda_{ą} + ((1- \lambda_{ą})*EWMA_{yesterday})$	$\frac{A}{A+B+C+D}$

Blanch and Gabbett (2016) have proposed that the ACWR could be used as a marker to identify the balance between fitness and fatigue. If the ratio is low (<1) then this indicates that the athlete has done less in the current week in comparison to their previous four weeks. However, if the ratio is high (>2) then this indicates that the athlete has done twice the amount of work in the current week (Gabbett, 2016). Acute chronic workload ratios in the range of 0.8 to 1.3 have been considered the training 'sweet spot', above and below which the risk of injury increases in specific sports (Gabbett, 2016). Hulin et al. (2014) found that cricket fast bowlers whose ACWR was greater than 1.5 were two to four times likely to sustain an injury (Windt & Gabbett, 2017). Sudden spikes in the acute training load, (i.e. >1.5) increases the risk of injury in the following week (Gabbett, 2016). This was also seen in rugby league players and professional soccer players (Windt & Gabbett, 2017). Maintaining the ACWR between 0.8 and 1.3 and maintaining week to week increases within 10%, may minimise the risk of injury. However, this research is not specific to ultramarathon runners. Figure 1 represents a guide for interpreting the acute:chronic workload ratio taken from three different sports namely; cricket, Australian football and rugby league (Gabbett, 2016).

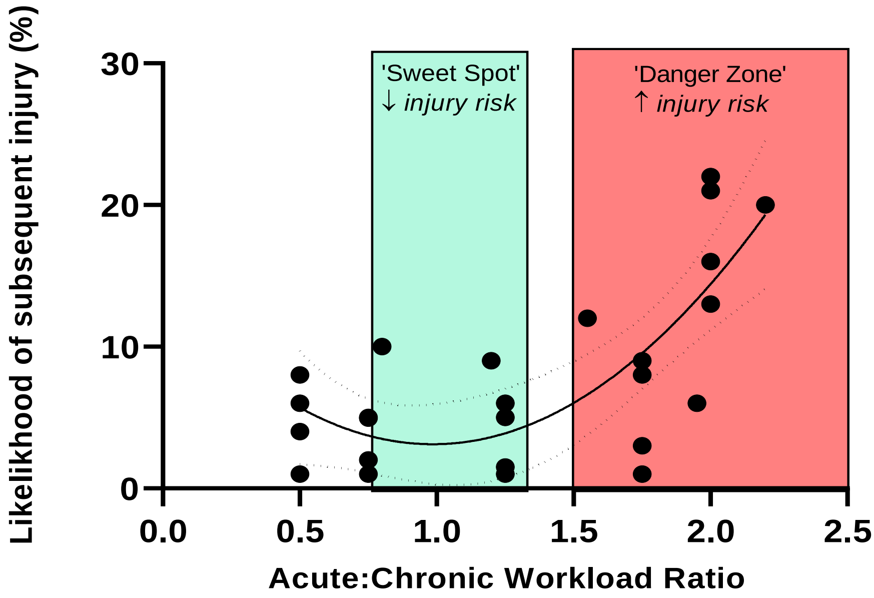

Figure 1: A guide to interpreting the acute chronic workload ratio. The green-shaded area represents the 'sweet spot' where the injury risk is low. The red-shaded area represents high acute chronic workload ratios where the injury risk is high (*adapted from Gabbett, 2016).*

A fine line exists between overtraining and undertraining therefore continuous monitoring of an athlete is imperative (Gabbett, 2016). Using variables that are specific to the sport at hand (e.g. distance for ultramarathon runners) in calculating the ACWR may prove to be beneficial in predicting future injury (Blanch & Gabbett, 2016). Until such time as reference values for ultramarathon runners are established, the current recommendations should be applied with caution specifically in individual sports.

As load has been found to be an important extrinsic risk factor to injury (Van Middelkoop et al., 2008), it would seem logical to deduce that there must be an optimal training load. This optimal training load would effectively minimise the risk of injury and illness and subsequently optimise performance. Currently, there is very little evidence to suggest what the optimal training load is for an endurance runner. From a clinical and sports performance perspective, it is difficult to make practical, evidence-based recommendations to runners due to conflicting evidence. Therefore, more research is needed in this field to accurately guide athletes and coaches in terms of their weekly training regimen so as to best prepare an athlete for an ultramarathon event.

2.6 Summary of the literature

Literature thus far has started to unravel the complex relationship between training loads, injury and illness profiles. After reviewing and analysing the above literature it is evident that there is a relationship between training loads, injury and illness, however, this relationship is non-linear and different for every individual athlete (Gabbett & Whiteley, 2017). Monitoring of athletes and endurance runners specifically is needed to contribute to the already existing pool of data on injury and illness risk. Therefore, constant monitoring of an athlete's response to the imposed load is imperative to minimise the risk of injury and illness and maximise performance.

The varying incidence of running-related injuries may be explained by the differences in injury definitions (Kluitenberg et al., 2016). While the anatomical site and type of structure most commonly affected in endurance runners is well documented (Knobloch et al., 2008; Van Gent et al., 2007), other factors that may predispose an athlete to injury require more research. Endurance sports are commonly monitored by examining the athlete's heart rate response, oxygen consumption and rating of perceived exertion as well as other parameters such as their weekly distance covered, duration and intensity of the training session. A combination of the above factors allows for better evaluation of the athlete's state of fitness or fatigue. However, the extent and range of these parameters and how they affect training and possibly future injury are unknown (Gabbett & Whiteley, 2017; Windt & Gabbett, 2017).

Current literature suggests that moderate intensity exercise may improve the immune system of sedentary and active individuals and potentially reduce the risk of sustaining illnesses such as URTI's common in endurance athletes. The nature of exercise that is most favourable is yet to be determined (Walsh et al., 2011). Conversely, prolonged, high intensity exercise may negatively impact the innate and acquired immune system and potentially increase the risk of infection and specifically URTI's. Gaps in the literature are evident with regard to the accurate measurement of immune function or dysfunction, the effect of biological and psychological stressors on the immune system and whether exercise affects disease susceptibility (Walsh et al., 2011).

According to Jones, Griffiths and Mallelieu (2017), higher chronic workloads overall are protective against injury. This in turn increases the athlete's injury threshold allowing them to train at these higher loads. Loading improves an athlete's ability to tolerate the demands of their respective sport (Bourdon et al., 2017). However, this is in conjunction with adequate rest and recovery (Bowen et al., 2017).

The ACWR, using the EWMA method of calculation for chronic load, has been considered an effective tool in the monitoring of an athlete's training load. This ratio allows athletes and coaches to identify sudden spikes in weekly training loads that may indicate increased risk of injury and illness in the following week (Williams et al., 2017).

As training load, injury and illness is multifactorial, other factors that affect loading have to be taken into account. These include but are not limited to: age, different body tissues, sleep and nutrition (Gabbett & Whiteley, 2017; Gleeson et al., 2004). However, investigation of these factors is beyond the scope of the current dissertation. The purpose of this dissertation is to establish potential associations between training loads, injury and illness in ultramarathon runners. Based on the findings of this study, we aim to add to current literature with regard to injury and illness profiles of ultramarathon runners as well as the use of internal training loads, external training loads and the EWMA of the ACWR in the monitoring and prevention of injury and illness in endurance runners.

CHAPTER 3: DOES A GREATER TRAINING LOAD INCREASE THE RISK OF INJURY OR ILLNESS IN ULTRAMARATHON RUNNERS?

3.1 Introduction

As the benefits of increasing exercise activity became recognized across the globe, the so called ‘exercise boom’ starting in the early 1980’s continued to grow (Taunton et al., 2002). However, with this rise in popularity so too has the risk of sustaining a running-related injury and illness increased (Rasmussen et al., 2013). Training errors have been associated with up to 70% of running-related injuries. Because training load is modifiable, these injuries resulting from training errors could be preventable (Nielsen et al., 2013).

To better understand the relationship between training load and injury or illness, the different training parameters which contribute toward the overall training load must be defined. The impact of both the internal and external training load placed on an athlete has been described. More recently, the effect of the relationship between the acute (weekly) and chronic (monthly) training loads (known as the acute:chronic workload ratio), has been identified. Identifying the effect of the acute training load and the chronic training load on an athlete’s risk of injury, illness and performance as well as its effect on predicting possible future injury is of paramount importance. To our knowledge, no studies have investigated training loads, injury and illness as a whole in recreational ultramarathon runners.

Therefore, the aim of this study was to determine if there were any associations between training loads, injury and illness profiles of ultramarathon runners. The specific objectives of this study are described in Chapter 1.

3.2 Study design and recruitment

The study had a prospective, descriptive, longitudinal design. Once ethical approval was obtained, ultramarathon runners who qualified for the 2019 Two Oceans ultramarathon race were recruited to this study. Permission was granted from the Two Oceans Race organisers to gain access to their database of runners. The specific sampling strategy chosen was sampling voluntary response. Only the email addresses of runners who had given consent to be contacted for future research purposes were shared with the researcher. This was in the form of a password protected excel spreadsheet. Recruitment then involved emailing entrants from this database. The manager of the researcher's running club was also approached with regard to this study. The manager of the running club sent out an email, including the recruitment flyer, to all club members (see Appendix A).

3.3 Participants

3.3.1 Inclusion criteria

Male and female runners over 20 years of age and who had qualified for the 2019 Two Oceans ultramarathon race were included in this study. Twenty years of age is the minimum age requirement for participation in an ultramarathon race in South Africa.

3.3.2 Exclusion criteria

Participants with relevant medical or surgical history that would prevent safe participation in running and participants who did not give written informed consent were excluded. Participants who completed the baseline questionnaire but did not complete the weekly logbooks were also excluded from this study. Participants who sustained a running-related injury within a seven-day period prior to the commencement of the 16-week monitoring period were excluded from the study. Participants could withdraw from the study at any time with no consequence for their withdrawal.

3.3.3 Sample size

A sample size calculation was performed using StatCalc (Epi Info 7.2). Sample size was calculated for a population survey. We used a population size of 11 000, based on the number of entrants for the 2018 Two Oceans Ultramarathon Race. We based the sample size calculation on an expected injury frequency of 30% and an acceptable margin of error of 5%. For confidence levels of 80%, 90% and 95%, the required sample size for this study was 136, 223, and 313 participants respectively.

3.4 Measurement instrumentation

3.4.1 Informed consent form

Participants were required to complete an informed consent form prior to the start of the study (Appendix B). All relevant information regarding the study purpose and procedures was included. The potential risks and benefits were described to the participants, as well as their right to withdraw from the study at any time should they so wish.

3.4.2 Physical activity readiness questionnaire

The Physical Activity Readiness Questionnaire (PAR-Q+) (Appendix C) was used to screen participants for any potential underlying medical and surgical conditions that may limit safe participation in physical activity. Participants who answered 'no' to all initial questions were cleared to take part in the study. Initial questions were related to the presence of any heart conditions, high blood pressure or other chronic medical related conditions, the use of prescription or chronic medication, chest pain at rest or during activity, dizziness or loss of balance in the past 12 months and current bone, joint or soft tissue problems that may worsen with increasing physical activity.

Participants who answered 'yes' to one or more of the initial questions then had to complete the follow up questions. If they further answered 'yes' to one or more of the follow-up questions participants were excluded from the study and advised to seek medical help.

The validity and reliability of the PAR-Q+ has been previously established (Warburton, Bredin, Jamnik, & Gledhill, 2011).

3.4.3 Baseline questionnaire

A self-developed questionnaire was used to establish participants' training, injury and illness history (Appendix D). Training, injury and illness history were based on self-reported training, injury and illness characteristics in the six-month period preceding the study.

The questionnaire was reviewed by a panel of experts to establish content and construct validity. The panel consisted of three colleagues with expertise in exercise and sports physiotherapy and exercise physiology. The expert panel gave input on the content, appropriateness and applicability of the questionnaire. The final questionnaire incorporated all suggestions from the expert panel.

Once the validation process was completed, the feasibility of the questionnaire was assessed through a pilot study of four participants. Pilot study participants were selected based on the inclusion and exclusion criteria for the main study. Participants were requested to provide feedback on their comprehension and ease of completion of the questionnaire. Minor changes to the questionnaire were then made based on the pilot study findings. This included clarifying complicated research terminology which was not understood by participants. Data from pilot study participants were not included for analysis, as they completed the baseline questionnaire only.

3.4.4 Training, injury and illness logbook

Participants kept a weekly logbook of their training, injury and health information for the 16-week study period, which comprised 12 weeks before the race and four weeks after the race (Appendix E).

Training information included average training distance ($km.week^{-1}$), duration ($min.week^{-1}$), and frequency ($sessions.week^{-1}$). Participants also recorded average weekly rate of perceived exertion (RPE), using the modified Borg scale (Borg, 1982).

Participants indicated if they had sustained a running-related injury each week.

Participants who sustained injuries recorded if the injury was new or recurrent, the injury type as well as the site of pain. Time-loss from running was also recorded. Time-loss was defined as stoppage of running for at least seven days or three or more consecutive training sessions missed (Yamato et al., 2015).

The injury severity was then classified according to a pain scale. Participants recorded their pain score out of 10 using a Visual Analogue Scale (VAS) (Boonstra, Schiphorst Preuper, & Reneman, 2008). A pain score of 0 to 4 was classified as 'mild', 5 to 7 was classified as 'medium' and 8 to 10 was classified as 'severe'.

Participants documented their weekly health status and if they had contracted any new or recurring illnesses. Participants who reported an illness were requested to document the associated symptoms, the influence of the illness on their participation in training and competition parameters, and any treatment that was received for the illness.

The logbook was distributed via email on Sunday of each week for 16 weeks (2nd February 2019 to 19th May 2019). The email contained a link to SurveyMonkey (www.surveymonkey.com), which enabled logbook responses to be completed online. Every second week, the online logbook was checked to monitor completion rates. Participants who had not completed the weekly logbook were then sent an email reminder.

3.4.5 Two Oceans ultramarathon race

The Two Oceans Ultramarathon Race took place on the 20th April 2019. The Two Oceans Ultramarathon is a 56km race through Cape Town allowing athletes seven and a half hours in which to complete the event. Gun to mat times are recorded in alignment with the IAAF rules and regulations. The route profile can be seen in Figure 2 below. The maximum elevation endured during the race was 300m.

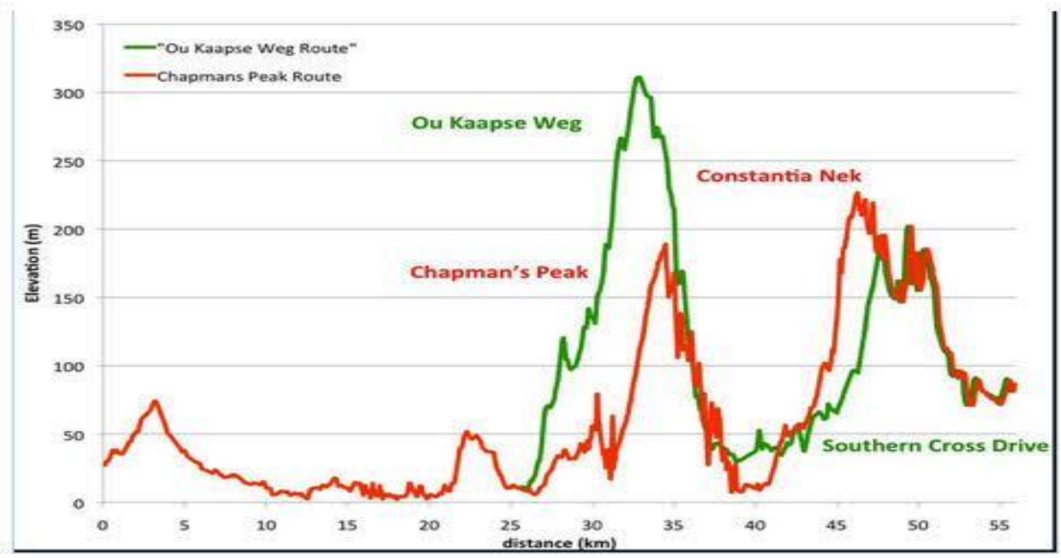

Figure 2: **Two Oceans Ultramarathon 2019 route profile** (Sunday Times, 2019).

3.5 Testing procedure

Participants who volunteered for the study gave written informed consent and completed the PAR-Q+ to ensure safe participation in this study (Appendices B and C). Participants then completed the baseline questionnaire to determine their training, injury and illness history for the six month period preceding the study (Appendix D). Thereafter, weekly training, injury and illness logbooks were completed for 12 weeks before the Two Oceans ultramarathon race and four weeks after the race (Appendices E and F). This was done via an electronic online platform (SurveyMonkey) to which all participants had access.

3.5.1 Data Analysis

3.5.1.1 Injury and illness incidence

Injury incidence was determined according to our definition of a running-related injury which was taken from the 2015 Consensus statement agreement (a modified Delphi approach) (Yamato et al., 2015).

A running-related injury was therefore constituted as; *"Running-related (training or competition) musculoskeletal pain in the lower limbs that causes a restriction on or stoppage of running (distance, speed, duration, or training) for at least seven days or three consecutive scheduled training sessions, or that requires the runner to consult a physician or other health professional"* (Yamato et al., 2015, p2). A new injury was defined as any new area of pain and/or the recurrence of a previous injury with more than a week's gap in symptoms. A recurring injury was defined as the same injury that the participant had experienced in the previous week. Injury proportion was calculated as the number of injured participants divided by the total sample size. Injury incidence was calculated as the number of injuries per 1000 hours of training.

Illness incidence was determined as *"A new or recurring illness incurred during competition or training receiving medical attention, regardless of the consequence with respect to absence from competition or training"* (Schwellnus et al., 2016, p1044). A new illness was defined as illness-related symptoms that the participant had not experienced in the previous week whereas a recurring illness pertained to illness-related symptoms that the participant had experienced in the previous week. Illness proportion was calculated by dividing the number of ill participants by the total sample size. Illness incidence was calculated as the number of ill participants per 1000 training days.

3.5.1.2 Training load calculations

Internal training loads were calculated by using the average intensity of their running sessions for the week, using the modified Borg scale, and the average cumulative duration of their sessions in minutes for the week (Gabbett, 2016). Internal training load was quantified by multiplying the RPE score by the duration resulting in exertional units.

External training load was presented as average cumulative mileage (kilometres) completed during the week. The acute:chronic workload ratio (ACWR) was calculated by dividing the average weekly external training load by the chronic external training load. The chronic training load was calculated using the exponentially weighted moving average (EWMA) method. The first acute:chronic ratio began after the second week of training using the EWMA calculation for the chronic load, and the last ratio was recorded after the full 16 weeks of training.

Odds ratios were used to determine any associations between four week training blocks (early training, mid training, pre-race and post-race) and internal and external training loads and injury and illness respectively. In addition they were used to determine any associations between the ACWR and injury and illness respectively.

The weekly internal training load was calculated as the average cumulative duration spent running per week ($min.wk^{-1}$) times the average session RPE per week, over the 16 weeks. Internal training loads of 3000 to 5000 exertional units have been reported previously in rugby union players but these values are significantly higher than internal training loads found in our study. Also, this is specific to a team sport which is therefore different for individual athletes.

As there is no reference value for ultramarathon runners in the literature thus far with regard to internal training load parameters, a weekly internal training load of ≥500 to <1000 exertional units was chosen as a reference value for the odds ratios calculations. This range is where the majority of participants' internal training loads fell.

As there is no reference value for ultramarathon runners in the literature with respect to external training load parameters, a weekly mileage of ≥30 to <60 kilometres per week was chosen as the reference value for the odds ratio calculations. A cumulative mileage of above $64km.wk^{-1}$ has been reported as higher risk for injury (Nielsen et al., 2012). Current literature proposes an ACWR reference value between 0.8 and 1.3 to minimise the risk of injury in the following week. Above 1.5 is suspected to increase the risk of injury significantly. However, as this ratio is not specific to running, a reference value of ≥1.0 to <1.5 was chosen as we would expect runners who are training for an ultramarathon to have higher chronic training loads based on previous research.

The EWMA is a relatively new method of calculating an athlete's chronic load. However, as this new method of calculation is proposed to be more sensitive than the original method of calculating the ACWR, this method has been used in our study. The EWMA of the ACWR can be calculated as follows:

$$*\mathbf{EWMA_{today} = Load_{today} * \lambda_a + ((1 - \lambda_a) * EWMA_{yesterday})}$$ (Williams et al., 2017).

3.5.2 Statistical Analyses

Statistical analyses were performed using Statistica (Version 13.5.0.17), Tableau (Version 2019.2), Prism (Version 8) and Python (Version 3.7.4) statistical software programmes. All data was assessed for normality using the Shapiro Wilk's test.

Descriptive characteristics of the study population were described using mean and standard deviation. Differences in descriptive data between the groups were assessed using an independent t-test. Baseline training data was described using mean and standard deviation. Baseline injury profiles were described using incidence percentages for the injured and uninjured groups. Similarly baseline illness profiles were described using incidence percentages for the ill and healthy groups. Incidence rates of overall and region-specific running-related injuries and illness were reported using percentages. Training parameters during the 16-week study period were described using mean and standard deviation for both the injured and uninjured groups, and the ill and healthy groups.

Weekly and cumulative absolute training load parameters were described using mean and standard deviation for the injured and uninjured groups, and the ill and healthy groups respectively. Weekly and cumulative relative training load parameters were described using mean and standard deviation for the injured and uninjured groups as well as the ill and healthy groups.

Significant difference in the training parameters between the injured and uninjured groups as well as the ill and healthy groups was measured using an independent t-test. A repeated measure ANOVA was used to determined differences in absolute training loads between groups over the 16 week period. Post-hoc analyses were performed using an unequal N HSD test.

Pearson's correlations and odds ratios were used to establish associations between injury, illness, and absolute and relative training load variables. Statistical significance was accepted as $p < 0.05$.

3.6 Ethical considerations

Ethical approval was obtained from the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee (HREC REF: 303/2017) (Appendix H). The study adhered to the ethical principles outlined in the Declaration of Helsinki (World Medical Association, 2013).

3.6.1 Autonomy and informed consent

Participants signed an informed consent form before participating in this study (Appendix A). The informed consent form provided details on the purpose of the study, the study procedures and risks and benefits of taking part in the study. Participants were informed that they could withdraw from the study at any time if they so wish, without any consequences.

3.6.2 Protection of individual privacy and confidentiality of data

All data from individual participants that was stored on SurveyMonkey was password-protected. Only the student researcher had access to personal identifying information (name and email address) of study participants.

Participants were coded so that no personal information was included in the data spreadsheet used for analysis. No participants will be identified in any publications arising from this dissertation.

All electronic data was stored in a password protected folder on the principle researcher's desktop computer and the student researcher's laptop computer. Electronic data was further protected through the use of encryption codes and passwords. Data will be stored for five years on completion of the dissertation.

3.6.3 Potential risks and benefits to participants

There were no risks and no direct benefits to participants associated with taking part in this study. As this study was monitoring the incidence of running-related injuries and illness, any participant who sustained an injury or illness was referred to an appropriate health care professional for further assessment and management if needed. Participants received feedback on the results which may help in the development of future training programmes and injury prevention programmes.

CHAPTER 4: RESULTS

4.1 Participants

One hundred and forty individuals were initially recruited for this study. Of the 140 prospective participants, 11 individuals did not return the consent forms. One hundred and twenty-nine participants consented to take part in the study. After inclusion and exclusion criteria were applied, 10 participants were excluded. Therefore a total of 119 participants took part in the study which is below the 80% CI calculated for this study. At baseline, there were 75 males and 43 females. After the study was completed, participants were divided into an injured (n=37) and uninjured group (n=82); and an ill (n=79) and a healthy group (n=40), based on individual injury or illness reported during the 16-week study period. The study sample is summarised in Figure 3.

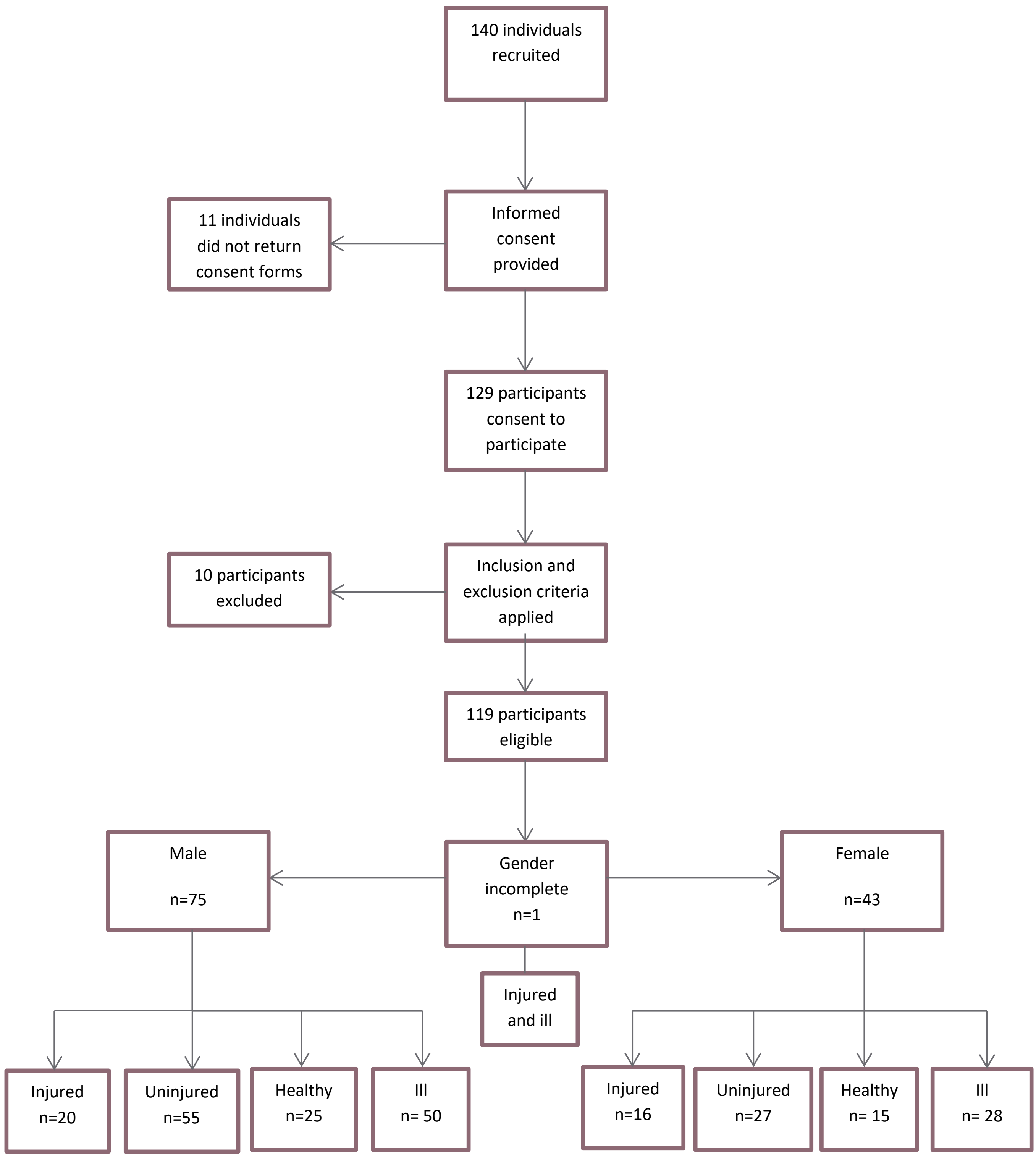

Figure 3: Summary of study sample.

4.2 Descriptive Characteristics

The descriptive characteristics of participants are shown in Tables 2 and 3 respectively. No significant differences were found for age, stature, body mass or BMI between the injured and uninjured groups. A significant difference was found in age between the healthy and ill groups (p=0.0025). The ill group was significantly younger than the healthy group.

Table 2: Descriptive characteristics of participants in the total, uninjured and injured groups. Data are presented as mean ± standard deviation (SD).

	Total Group (n=119)	**Uninjured (n=82)**	**Injured (n=37)**	**t-value**	**p-value**
Age (years)	41.00 ± 9.70	41.49 ± 9.37	40.00 ± 10.46	0.77	0.44
Stature (cm)	174.50 ± 9.38	175.33 ± 8.54	172.65 ± 10.92	1.45	0.15
Body mass (kg)	71.33 ± 12.57	71.62 ± 12.25	70.70 ± 13.40	0.37	0.72
BMI ($kg.m^2$)	23.08 ± 3.37	22.88 ± 3.70	23.52 ± 2.47	0.96	0.34

Table 3: Descriptive characteristics of participants in the total, healthy and ill groups. Data are presented as mean ± standard deviation (SD).

	Total Group (n=119)	**Healthy (n=40)**	**Ill (n=79)**	**t-value**	**p-value**
Age (years)	41.00 ± 9.70	42.53 ± 9.35	36.34 ± 9.44	3.09	**0.0025***
Stature (cm)	174.50 ± 9.38	174.76 ± 9.07	173.69 ± 10.42	0.53	0.60
Body mass (kg)	71.33 ± 12.57	71.06 ± 12.45	72.21 ± 13.15	0.42	0.67
BMI ($kg.m^2$)	23.08 ± 3.37	22.92 ± 5.05	23.53 ± 2.46	0.08	0.94

*p<0.05

4.3 Training and competition history

The training history of participants in the six month period preceding the study is presented in Tables 4 and 5. There were no significant differences between groups in any training history characteristics.

Table 4: Training history (average distance, average duration, average frequency and average endurance running experience) of the total, injured and uninjured groups six months prior to the start of the study. Data are presented as mean ± standard deviation (SD).

	Total Group (n=119)	Uninjured (n=82)	Injured (n=37)	t-value	p-value
Average distance ($km.wk^{-1}$)	50.9 ± 31.8	48.6 ± 30.2	56.3 ± 35.0	1.2	0.2
Average duration ($min.wk^{-1}$)	281.5 ± 160.5	271.6 ± 136.9	304.4 ± 205.7	1.0	0.3
Frequency ($sessions.wk^{-1}$)	4 ± 1	4 ± 1	4 ± 1	0.6	0.6
Endurance running (years)	11.2 ± 9.5	11.6 ± 9.5	9.9 ± 9.6	0.8	0.5

Table 5: Training history (average distance, average duration, average frequency and average endurance running experience) of the total, healthy and ill groups six months prior to the start of the study. Data are presented as mean ± standard deviation (SD).

	Total Group (n=119)	Healthy (n=40)	Ill (n=79)	t-value	p-value
Average distance ($km.wk^{-1}$)	50.9 ± 31.8	53.1 ± 32.4	44.1 ± 29.2	1.3	0.2
Average duration ($min.wk^{-1}$)	281.5 ± 160.5	287.9 ± 158.4	257.3 ± 169.1	0.8	0.4
Frequency ($sessions.wk^{-1}$)	4 ± 1	4 ± 1	4 ± 1	0.4	0.7
Endurance running (years)	11.2 ± 9.5	11.4 ± 9.9	10.6 ±8.9	0.4	0.7

Of the 119 participants, 33 participants (28%) reported that the 2019 Two Oceans Ultramarathon event was their first ultramarathon race. A further five participants indicated that they had not completed the Two Oceans ultramarathon race before but that they had completed other ultramarathons. The remaining 86 participants had completed an average of 10.05 ± 21.53 ultramarathons prior to the 2019 Two Oceans race.

4.4 Injury and illness history

The incidence proportion of running-related injuries in the six-month period preceding the study was 23%. The injury incidence was 8 per 1000 hours of training. Tendons (22%) and muscles (22%) were the most commonly reported structures involved in injuries; whilst the foot (19%) and ankle (19%) were the most common injury sites. The incidence proportion of illness in the six-month period prior to the study was 24%. The most common illness-related symptoms were congestion (34%), sore throat (29%) and stomach problems (22%).

4.5 Two Oceans 2019 Race Performance times

The performance times of participants for the 2019 Two Oceans Ultramarathon event are presented in Table 6 below. On average, no significant difference was found between the injured and uninjured group and the healthy and ill group when comparing marathon (42.2km) and ultramarathon (56km) race finishing times.

Table 6: Marathon (42.2km) and Ultramarathon (56km) average race finishing times (hrs) for the injured and uninjured groups and the ill and healthy groups. Data are presented as mean ± standard deviation (SD).

Race Times	Injured (n=37)	Uninjured (n=82)	Ill (n=79)	Healthy (n=40)
42.2km (hrs:min:sec)	4:24:14 ± 0:32:50	4:22:06 ± 0:32:32	4:24:24 ± 0:31:14	4:18:41 ± 0:35:12
56km (hrs:min:sec)	6:06:48 ± 0:46:13	6:00:32 ± 0:46:31	6:05:31 ± 0:44:58	5:55:46 ± 0:49:03

4.6 Injury profile over the 16 weeks

The weekly injury proportions are shown in Figure 4. The overall injury incidence proportion over the 16 weeks was 31%. The highest weekly injury proportion (7%) occurred in week 13, which was one week following the ultramarathon race. There were a total of 71 injuries recorded over the 16 week study time period. Of the injuries sustained, 56 were new injuries and 15 were recurrent injuries. The overall injury incidence was 5 per 1000 hours of training.

The average time-loss from injury was 3 ± 2 missed training sessions. The VAS scale was used to classify the participant's pain intensity and therefore the severity of their injury. A total of 53% participants reported their pain as mild (0-4), 39% classified their pain as moderate (5-7) and 8% classified their pain as severe (8-10).

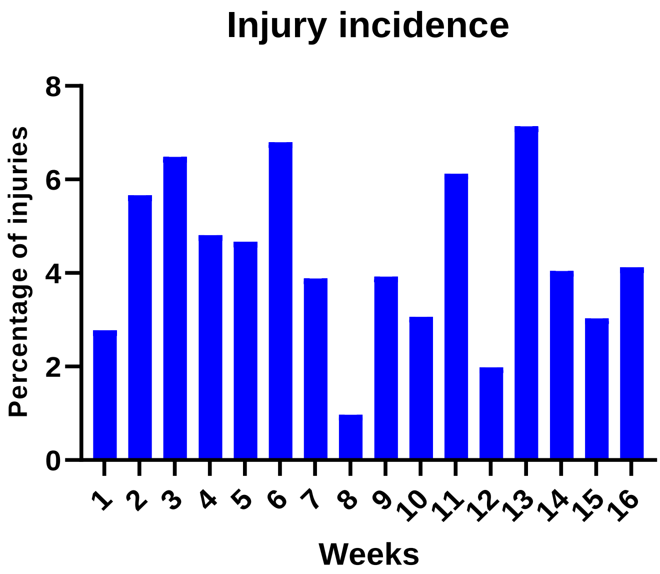

Figure 4: Injury incidence (percentage) per week over the 16 week study period.

4.6.1 Type of structure injured, anatomical location and time-loss from injury

Figure 5 represents the main type of structure injured over the 16 weeks. The most commonly injured structure was muscle (37%).

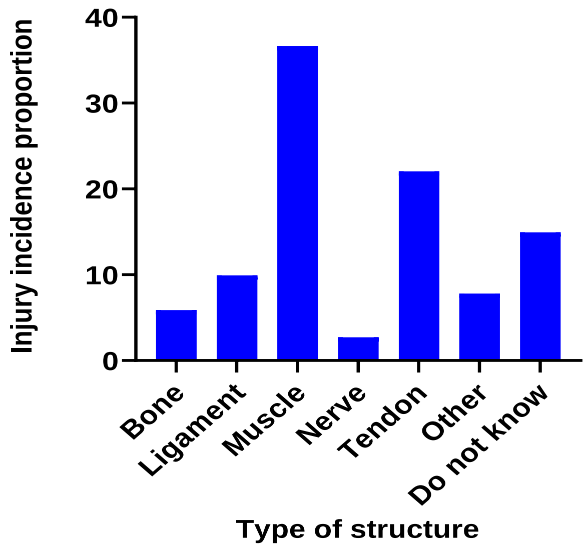

Figure 5: Main type of structure injured over the 16 weeks.

Figure 6 represents the main anatomical area of pain reported over the 16 weeks. The knee was the most common site of pain (19%), followed by the foot (14%), hip (12%) and ankle (12%).

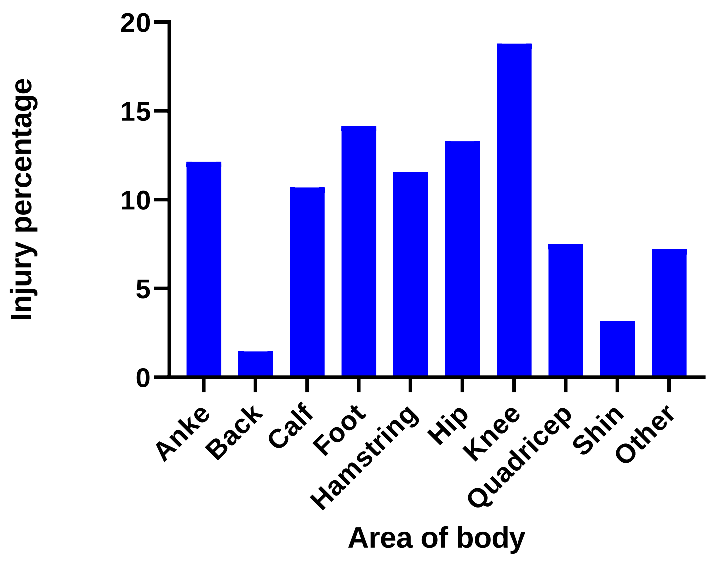

Figure 6: Anatomical location most commonly injured over the 16 weeks.

4.7 Illness profile over the 16 weeks

The weekly illness proportions are depicted in Figure 7. The overall illness proportion was 66%. There was a spike in illness incidence in weeks 13 and 14 (22% and 20% respectively), which are one and two weeks respectively post the Two Oceans Ultramarathon race. The overall illness incidence was 16 per 1000 training days. The average time-loss due to illness was 3 ± 1 training session missed. The main illness-related symptoms that were reported were congestion (54%) and fatigue (20%).

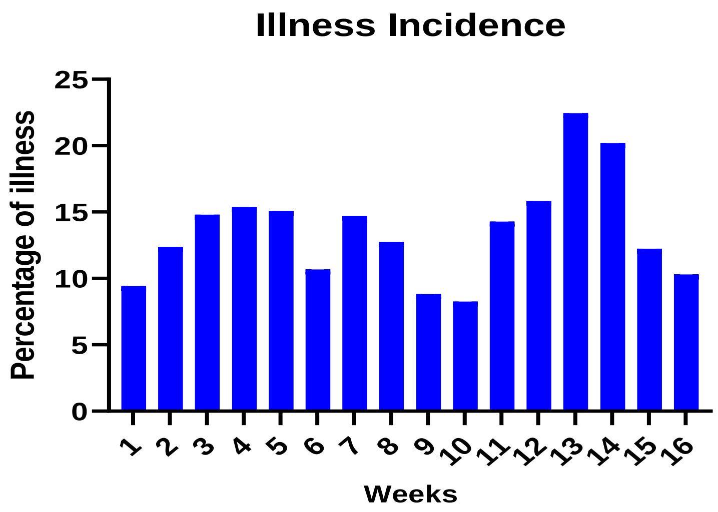

Figure 7: Illness incidence per week over the 16 week study period.

4.8 Training parameters over the 16 weeks

No significant difference was found between the injured and uninjured group in average cumulative distance and average cumulative duration per week. A significant difference was found between the two groups for average frequency (p=0.0286) and average sessional RPE per week (p=0.0030) (Table 7). On average, the uninjured group ran significantly more times per week than the injured group and at a significantly higher intensity.

Table 7: Training parameters (average distance, average duration, average frequency and average session RPE) between the total, uninjured and injured groups over the 16 week study time period. Data are presented as mean ± standard deviation (SD).

	Total group (n=119)	Uninjured (n=82)	Injured (n=37)	t-value	p-value
Distance ($km.wk^{-1}$)	52.20 ± 38.30	54.18 ± 31.22	44.32 ± 21.67	1.74	0.08
Duration ($min.wk^{-1}$)	131.80 ± 129.30	125.80 ± 83.34	128.10 ± 88.06	0.13	0.89
Frequency ($sessions.wk^{-1}$)	4 ± 2	4 ± 1	3 ± 1	2.23	**0.0286***
Average session RPE (0-10)	4 ± 2	5 ± 1	4 ± 1	3.07	**0.0030****

*p<0.05: indicates significant difference found

**p<0.001: indicates significant difference found

No significant difference was found between the healthy and ill group in average cumulative distance, average cumulative duration, average frequency and average sessional RPE per week (Table 8).

Table 8: Training parameters (average distance, average duration, average frequency and average session RPE) between the total, healthy and ill groups over the 16 week study time period. Data are presented as mean ± standard deviation (SD).

	Total Group (n=119)	Healthy (n=40)	Ill (n=79)	t-value	p-value
Distance ($km.wk^{-1}$)	52.20 ± 38.30	51.91 ± 22.04	50.79 ± 31.30	0.22	0.83
Duration ($min.wk^{-1}$)	131.80 ± 129.30	110.90 ± 70.68	132.70 ± 89.00	1.41	0.16
Frequency ($sessions.wk^{-1}$)	4 ± 2	4 ± 1	4 ± 1	1.15	0.26
Average sessions RPE (0-10)	4 ± 2	4 ± 1	4 ± 1	0.30	0.76

4.8.1 Weekly internal training load (duration X RPE)

The weekly internal training load for the injured and uninjured groups is shown in Figure 8. Week 12 corresponds with the Two Oceans ultramarathon race which had the highest internal training load of 1384 ± 1086.8 exertional units in the injured group and 1227 ± 1033.8 in the uninjured group. The injured group's average internal training load over the 16 weeks was 564 ± 732.7 exertional units and the uninjured group's average internal training load over the 16 weeks was 666 ± 745.7 exertional units.

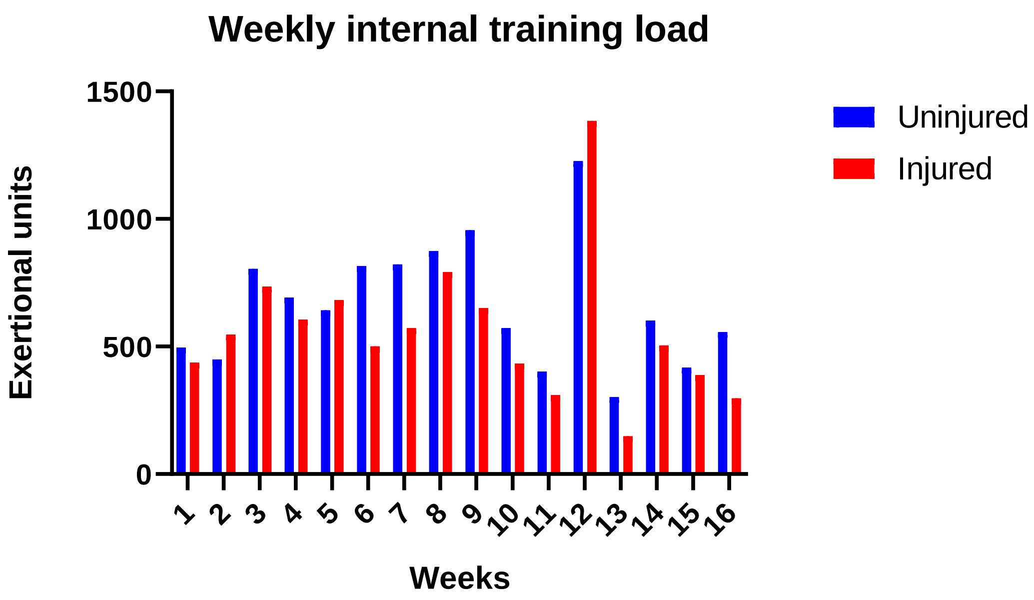

Figure 8: Average weekly internal training load between the injured and uninjured group over the 16 week study time period in exertional units.

The weekly internal training load for the healthy and ill groups is shown in Figure 9. Week 12 had the highest internal training load of 1295 ± 1095.3 in the ill group and 1209 ± 864.1 in the healthy group. The ill group's average internal training load over the 16 weeks was 663 ± 786.6 exertional units and the healthy group's average internal training load over the 16 weeks was 533 ± 554.8 exertional units.

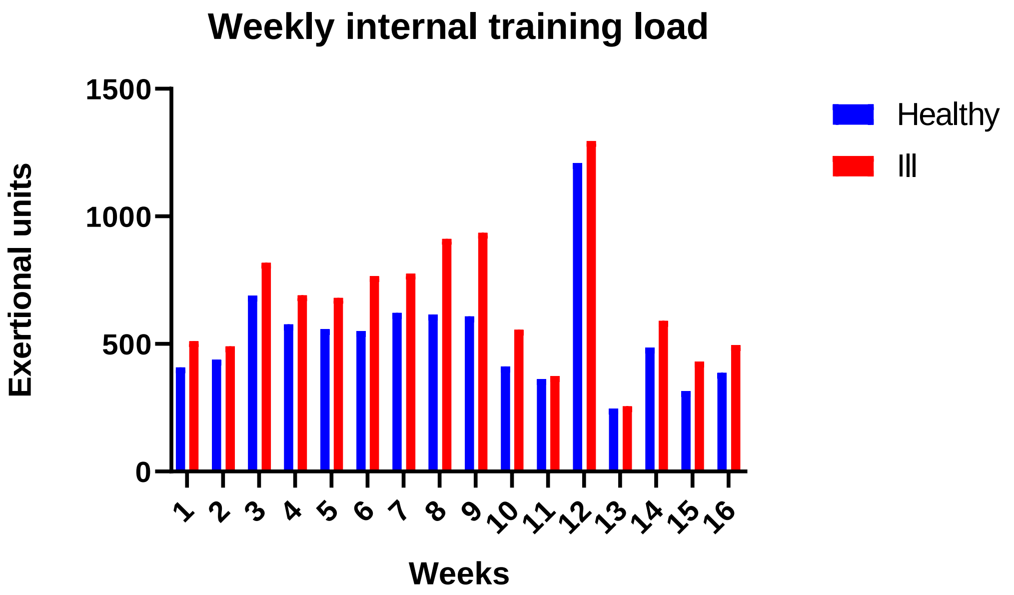

Figure 9: Average weekly internal training load between the healthy and ill group over the 16 week study time period in exertional units.

Figure 10 shows weekly internal training loads for participants in the injured and uninjured groups. There were no significant differences in internal training load between groups. However, there was a significant main effect of time $F_{(15, 1755)}$ =16,4; p=0.00001. Internal training loads were significantly higher in week 12 compared to weeks 1, 2, 4, 5, 10, 11 and 13 to 16; and significantly lower in week 13 compared to weeks 3, 7 to 9 and 12.

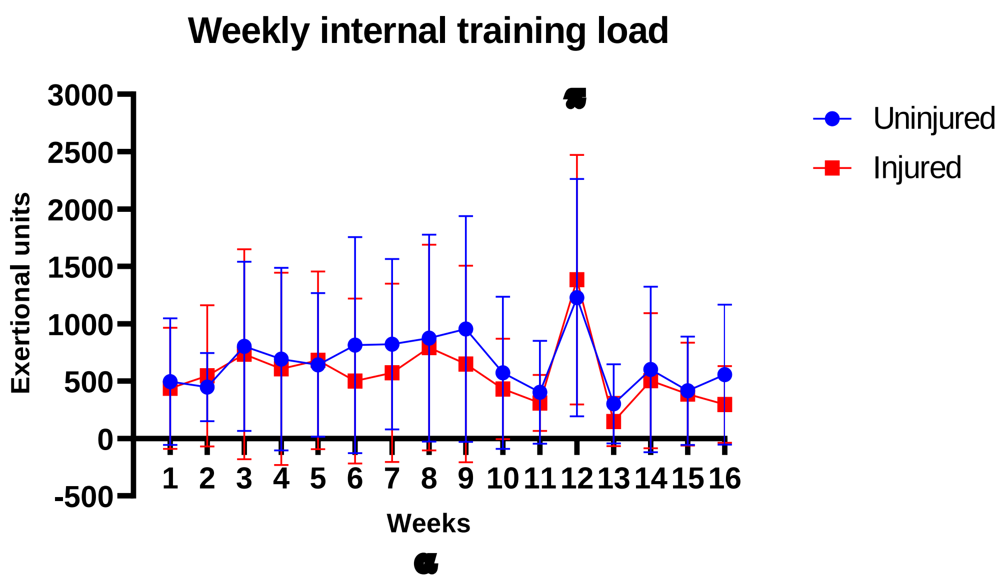

Figure 10: Differences in weekly average internal load between the injured and uninjured group over the 16 week study time period; π= race week.

α= Main effect of time: $F_{(15, 1755)}$ =16.4; p=0.00001

Week 12 vs Week 1, 2, 4, 5, 10, 11 and 13 to 16; (p<0.05)

Week 13 vs Week 3, 7 to 9 and 12; (p<0.05)

Figure 11 shows weekly internal training loads for participants in the ill and healthy groups. A significant main group effect in internal training loads was found $F_{(1,117)}$ =4,6; p=0.034. Internal training load was significantly higher in the healthy group in week 12 compared to the ill group (p<0.05). A significant main effect of time was also found $F_{(15,1755)}$ =15,7; p=0.00001. Internal training loads were significantly different in week 8 compared to weeks 1, 2 10 to 13, 15 and 16; in week 9 compared to week 1, 2, 10 to 13, 15, 16 ; in week 11 compared to week 3, 6 to 9, 12 ; in week 12 compared to all others weeks (p<0.05) and in week 13 compared to week 3 to 9 and week 12.

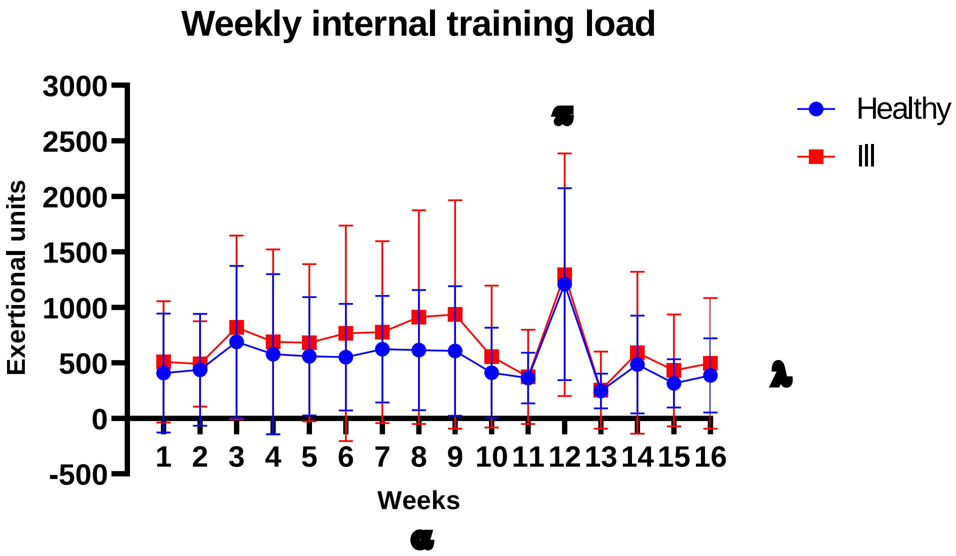

Figure 11: Differences in weekly average internal load between the ill and healthy group over the 16 week study time period; π= race week.

α= Main effect of time: $F_{(15, 1755)}$ =15,7; p=0.00001

λ= Group effect: $F_{(1, 117)}$ = 4,6; p=0.034

Week 8 vs Week 1, 2, 10 to 13, 15, 16; p<0.05

Week 9 vs Week 1, 2, 10 to 13, 15, 16; p<0.05

Week 11 vs Week 3, 6 to 9, 12 p<0.05

Week 12 vs Week 1, 2, 4, 5, 10, 11, 13-16; p<0.05

Week 13 vs Week 3, 7 to 9 and 12; p<0.01

4.8.2 Weekly external training load (distance)

The weekly external training load of the injured and uninjured groups are shown in Figure 12. Week 12 corresponds with the Two Oceans ultramarathon race which had the highest external training load of 64.8 ± 22.0 km.wk^{-1} in the injured group and 72.2 ± 22.9 km.wk^{-1} in the uninjured group. The injured group's average external training load over the 16 weeks was 44.5 ± 30.9 km.wk^{-1} and the uninjured group's external training load over the 16 weeks was 55.7 ± 40.7 km.wk^{-1}.

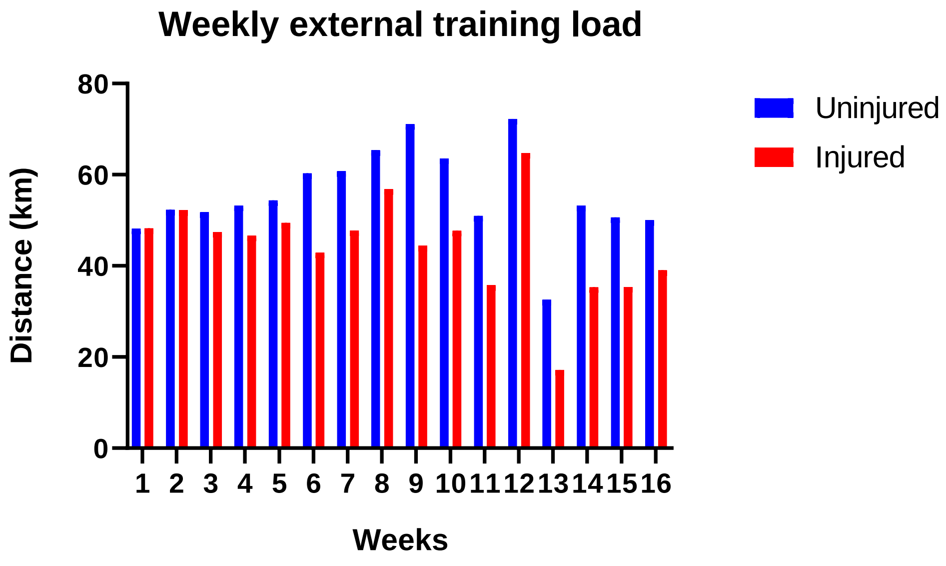

Figure 12: Average weekly external training load between the injured and uninjured group over the 16 week study time period in kilometres.

The weekly external training load of the healthy and ill group is shown in Figure 13. Week 12 had the highest external training load of 69.6 ± 23.9 $km.wk^{-1}$ in the ill group and 70.8 ± 15.7 $km.wk^{-1}$ in the healthy group. The ill group's average external training load over the 16 weeks was 52.1 ± 40.7 $km.wk^{-1}$ and the healthy group's average external training load over the 16 weeks was 52.4 ± 28.2 $km.wk^{-1}$.

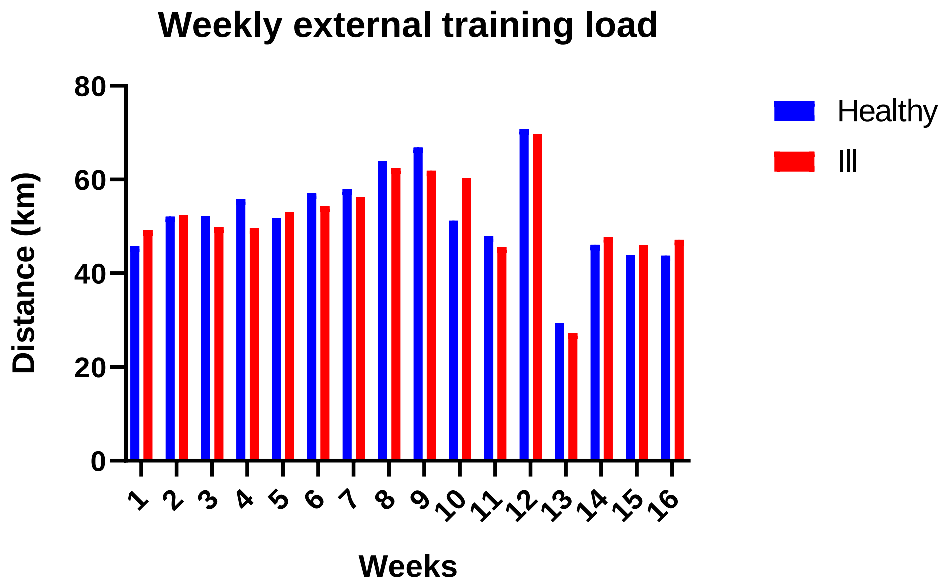

Figure 13: Average weekly external training load between the healthy and ill group over the 16 week study time period in kilometres.

Figure 14 shows weekly external training loads for participants in the injured and uninjured groups. There were no significant differences in external training load between groups. However, there was a significant main effect of time ($F_{(15, 1035)}$ =11.1; p=0.00001). External training loads were significantly higher in week 12 compared to weeks 13 to 16; and significantly lower in week 13 compared to weeks 2 to 10, 13, 14 and 16.

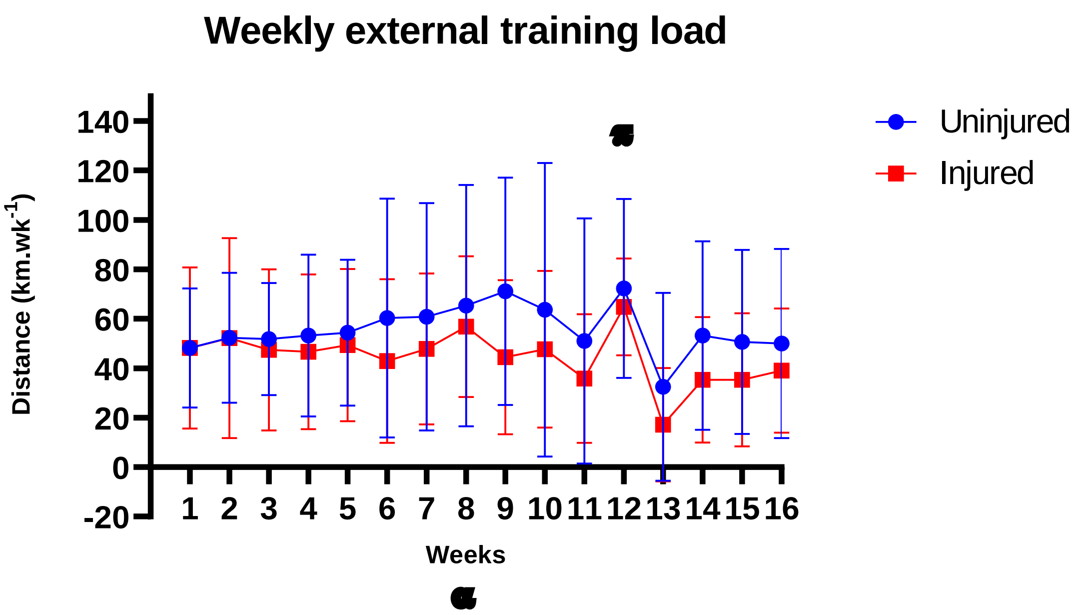

Figure 14: Differences in weekly average distance between the injured and uninjured group over the 16 week study time period; π= race week.

α= Main effect of time: $F_{(15, 1035)}$ =11.1; p=0.00001

Week 12 vs Week 13-16; p<0.05

Week 13 vs Week 2-10 ,13,14 and 16; p<0.05

Figure 15 shows weekly external training loads for participants in the healthy and ill groups. There were no significant differences in external training load between groups. However, there was a significant main effect of time ($F_{(15, 1035)}$ =5.7; p=0.000001). External training loads were significantly higher in week 12 compared to weeks 1 to 4, 11, 13 to 16; and significantly lower in week 13 compared to week 1 to 14 and week 16.

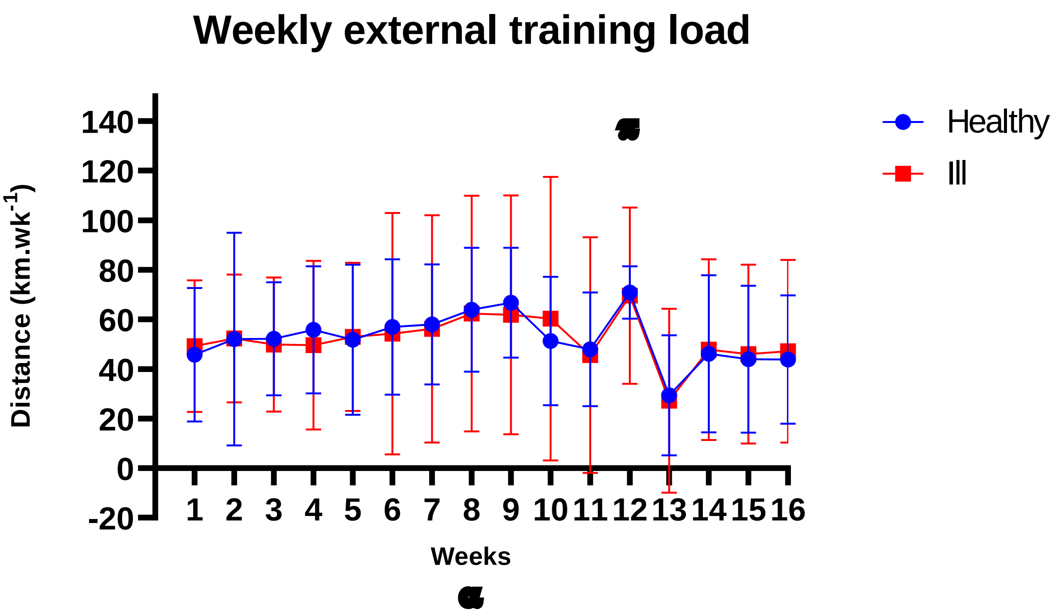

Figure 15: Differences in weekly average distance between the healthy and ill group over the 16 week study time period; π = race week.

α = Main effect of time: $F_{(15, 1035)}$ =5,7;, p=0,000001

Week 12 vs Week 1-4, 11, 13-16; p<0.05

Week 13 vs Week 1-14 and 16; p<0.02

4.8.3 Exponentially Weighted Moving Average of the Acute Chronic Workload Ratio's

The descriptive statistics for weekly ACWRs for the injured and uninjured groups are shown in Table 9. A significant difference was found between the uninjured and injured groups ACWR in week 10 (p=0.01). The injured group's ACWR was significantly lower in week 10 in comparison to the uninjured group's ACWR.

Table 9: Average weekly ACWRs for the injured and uninjured groups over the 16 week study time period. Data are presented as mean ± standard deviation (SD).

Week	Total group (n= 119)	Uninjured (n= 82)	Injured (n= 37)	t-value	p-value
1	1	1	1	Na	<0.0001
2	0.83	0.86	0.79	1.08	0.28
3	0.92	0.94	0.89	0.83	0.41
4	0.91	0.95	0.82	1.71	0.09
5	0.85	0.83	0.92	0.74	0.46
6	0.92	0.86	1.04	1.92	0.06
7	0.85	0.89	0.75	1.56	0.12
8	0.89	0.88	0.92	0.51	0.61
9	0.93	0.89	1.01	1.22	0.22
10	0.88	0.96	0.72	2.54	**0.01***
11	0.77	0.75	0.83	0.87	0.38
12	0.68	0.66	0.72	0.83	0.41
13	1.04	1.00	1.13	1.24	0.22
14	0.40	0.43	0.33	1.34	0.18
15	0.76	0.77	0.75	0.16	0.87
16	0.74	0.73	0.78	0.63	0.53

The descriptive statistics for weekly ACWRs for the ill and healthy groups are shown in Table 10. A significant difference was found between the ill and healthy groups ACWR in week 3 (p=0.03), 6-9 (p<0.001; p=0.05; p=0.01; p=0.01), 11-13 (p<0.001; p=0.002; p=0.0002), 15 (p=0.0001) and 16 (p<0.0001). The ill group's weekly ACWR was significantly higher than the healthy groups weekly ACWR in all the above weeks.

Table 10: Average weekly ACWRs for the ill and healthy groups over the 16 week study time period. Data are presented as mean ± standard deviation (SD).

Week	Total group (n= 119)	Healthy (n= 79)	Ill (n= 40)	t-value	p-value
1	1	1	1	Na	<0.0001
2	0.83	0.76	0.88	1.31	0.19
3	0.92	0.79	0.99	2.27	**0.03***
4	0.91	0.91	0.92	0.04	0.97
5	0.85	0.79	0.89	1.06	0.29
6	0.92	0.68	1.04	4.16	**<0.0001****
7	0.85	0.73	0.91	2.01	**0.05***
8	0.89	0.74	0.97	2.629	**0.01****
9	0.93	0.75	1.01	2.83	**0.01****
10	0.88	0.77	0.94	1.83	0.07
11	0.77	0.54	0.89	4.1	**<0.0001****
12	0.68	0.52	0.76	3.12	**0.002****
13	1.04	0.80	1.16	3.9	**0.0002****
14	0.40	0.34	0.43	1.2	0.23
15	0.76	0.52	0.88	3.94	**0.0001****
16	0.74	0.51	0.86	4.04	**<0.0001****

4.8.4 Relationships between internal and external training loads, and injury incidence

There were no significant associations between weekly internal training load and injury incidence proportions. However, there was a significant negative association between weekly external training load and injury incidence proportions (r=-0.56; p=0.025). As external training load decreased, injury incidence proportions increased.

4.8.5 Relationships between internal and external training loads, and illness incidence

There were no significant associations between weekly internal training load and illness incidence proportions. There were also no significant associations between weekly external training load and illness incidence proportions.

4.8.6 Odds ratio for internal training load and injury incidence

The associations between the internal training load and injury, as per four week training blocks, were investigated using odds ratios (OR) as shown in Table 11. No significant relationships were found for internal training load and injury incidence.

Table 11: Odds ratio table for risk factors for injury incidence and internal training loads.

Internal		**Week 1 to 4 (Early training)**		**Week 5 to 8 (Mid training)**		**Week 9 to 12 (Pre-race)**		**Week 13 to 16 (Post-race)**	
Reference (exertional units)	**Internal load (distance X RPE)**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**
≥500 - <1000 (EU)	≥0 - < 500	0.86 (0.40 - 1.88)	0.71	0.40 (0.13 - 1.26)	0.12	1.53 (0.33 - 7.02)	0.59	1.20 (0.14 - 10.20)	0.86
	≥500 - <1000	1.00		1.00		1.00		1.00	
	≥1000 - <1500	0.70 (0.18 - 2.77)	0.61	0.83 (0.15 - 4.52)	0.83	1.31 (0.11 - 14.93)	0.83	1.61 (0.06 - 42.03)	0.78
	≥1500 - <2000	0.23 (0.01 - 4.19)	0.32	0.63 (0.07 - 5.72)	0.69	1.05 (0.05 - 22.99)	0.97	7.40 (0.24 - 231.34)	0.25
	≥2000	0.95 (0.24 - 3.85)	0.95	0.19 (0.01 - 3.50)	0.26	3.20 (0.51-19.94)	0.21	2.18 (0.08-57.90)	0.64

*p<0.05

**p<0.0001

4.8.7 Odds ratio for internal training load and illness incidence

The associations between internal training load and illness, as per four week training blocks, was measured with odds ratios (OR) as shown in Table 12. No significant relationships were found for internal training load and illness incidence.

Table 12: Odds ratio table for risk factors for illness incidence and internal training loads.

Internal		**Week 1 to 4 (Early training)**		**Week 5 to 8 (Mid training)**		**Week 9 to 12 (Pre-race)**		**Week 13 to 16 (Post-race)**	
Reference (exertional units)	**Internal load (distance X RPE)**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**
≥500 - <1000 (EU)	≥0 - < 500	0.98 (0.46 - 2.06)	0.95	0.89 (0.42 - 1.87)	0.75	0.89 (0.45 - 1.76)	0.74	1.49 (0.59 - 3.77)	0.39
	≥500 - <1000	1.00		1.00		1.00		1.00	
	≥1000 - <1500	1.38 (0.46 - 4.2)	0.57	0.76 (0.23 - 2.57)	0.66	1.52 (0.55 - 4.23)	0.42	1.85 (0.32 - 10.66	0.49
	≥1500 - <2000	0.46 (0.05-3.93)	0.48	0.29 (0.03 - 2.33)	0.24	0.77 (0.16 - 3.79)	0.75	1.55 (0.07 - 36.06)	0.78
	≥2000	0.29 (0.03-2.37)	0.25	1.57 (0.55 - 4.46)	0.40	0.71 (0.24-2.14)	0.55	1.19 (0.12 - 11.41)	0.88

4.8.8 Odds ratio for external training load and injury incidence

The associations between external training load and injury, as per four week training blocks, was measured with odds ratios (OR) as shown in Table 13. A significant relationship was found for external training load and injury incidence in weeks 5 to 8 for those who ran <30.0km.wk^{-1} (p=0.0047; OR: 2.00 to 46.75)).

Table 13: Odds ratio table for risk factors for injury incidence and external training loads.

External		Week 1 to 4 (Early training)		Week 5 to 8 (Mid training)		Week 9 to 12 (Pre-race)		Week 13 to 16 (Post-race)	
Reference ($km.wk^{-1}$)	**Exposure group ($km.wk^{-1}$)**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**
≥30.00 - <60.00	≥0.00 - <30.00	1.31 (0.64 - 2.70)	0.46	9.68 (2.00 - 46.75)	**0.0047****	3.37 (0.98 - 11.61)	0.0540	2.18 (0.24 - 19.83)	0.49
	≥30.00 - <60.00	1.00		1.00		1.00		1.00	
	≥60.00 - <90.00	0.58 (0.25 - 1.35)	0.20	4.47 (0.89 - 22.56)	0.07	0.79 (0.19 - 3.21)	0.74	1.51 (0.09 - 24.72)	0.77
	≥90.00 - <120.00	0.47 (0.06 - 3.75)	0.48	0.87 (0.04 - 18.49)	0.93	0.38 (0.02 - 7.26)	0.52	1.01 (0.04 - 25.70	0.99
	≥120.00	2.17 (0.42 - 11.10)	0.35	2.91 (0.13 - 64.32)	0.50	3.28 (0.33 - 32.49)	0.31	3.82 (0.14 - 103.53)	0.43

**p<0.01

4.8.9 Odds Ratio for external training load and illness incidence.

The associations between external training load and illness, as per four week training blocks, was measured with odds ratios (OR) as shown in Table 14. A significant relationship was found between external training load and illness incidence in weeks 5 to 8, 9 to 12 and 13 to 16 for those who ran <30.00km.wk^{-1} (p = 0.0176; OR: 1.1570 to 4.6069; p= 0.0067; OR: 1.3420 to 6.2289 and p= 0.0001; OR 2.3183 to 12.3249).

Table 14: Odds ratio table for risk factors for illness incidence and external training loads.

External		Week 1 to 4 (Early training)		Week 5 to 8 (Mid training)		Week 9 to 12 (Pre-race)		Week 13 to 16 (Post-race)	
Reference group ($km.wk^{-1}$)	**Exposure group ($km.wk^{-1}$)**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**
30.00 - <60.00	≥0.00 - <30.00	1.57 (0.84 - 2.93)	0.16	2.31 (1.16 - 4.61)	**0.02***	2.89 (1.34 - 6.23)	**0.01****	5.35 (2.32 - 12.32)	**0.0001****
	≥30.00 - <60.00	1.00		1.00		1.00		1.00	
	≥60.00 - <90.00	0.54 (0.25 - 1.15)	0.11	1.03 (0.50 - 2.08)	0.94	0.84 (0.38 - 1.86)	0.66	1.06 (0.32 - 3.47)	0.93
	≥90.00 - <120.00	0.74 (0.16 - 3.39)	0.69	0.60 (0.17- 2.14)	0.43	0.81 (0.22 - 3.03)	0.75	1.57 (0.38 - 6.49)	0.53
	≥120.00	0.69 (0.08 - 5.72)	0.73	0.70 (0.09 - 5.79)	0.74	0.39 (0.02 - 6.97)	0.52	1.77 (0.19 - 16.20)	0.61

*p<0.05

**p<0.01

4.8.10 Odds ratio for ACWR and injury incidence.

The associations between the ACWR and injury, as per four week training blocks, was measured with odds ratios (OR) as shown in Table 15. A significant relationship was found between ACWR and injury incidence in weeks 1 to 4, 5 to 8 and 13 to 16 when the ACWR was ≥1.5 - <2 and >2 (p= 0.0001, OR: 15.17 (3.85 - 59.79); p= 0.03, OR: 31.00 (1.75 - 547.97) and p=0.03, OR: 5.73 (1.20 - 27.52) respectively).

Table 15: Odds ratio table for risk factors for injury incidence according to ACWR's.

ACWR		**Week 1 to 4 (Early training)**		**Week 5 to 8 (Mid training)**		**Week 9 to 12 (Pre-race)**		**Week 13 to 16 (Post-race)**	
Reference	**ACWR ratios**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**
≥1.00 - <1.50	≥0.00 - <0.50	3.10 (0.98 - 9.84)	0.0546	1.01 (0.26 - 3.99)	0.99	0.38 (0.08 - 1.79)	0.22	0.70 (0.15 - 3.18)	0.64
	≥0.50 - <1.00	0.90 (0.23 - 3.45)	0.88	1.40 (0.46 - 4.25)	0.55	0.40 (0.11 - 1.51)	0.18	0.91 (0.20 - 4.15)	0.90
	≥1.00 - <1.50	1.00		1.00		1.00		1.00	
	≥1.50 - <2.00	15.17 (3.85 - 59.79)	**0.0001****	0.94 (0.05 - 17.15)	0.96	1.88 (0.22 - 16.19)	0.57	5.73 (1.20 - 27.52)	**0.03***
	≥2.00	10.73 (0.41 - 282.95)	0.16	31.00 (1.75 - 547.97)	**0.02***	6.54 (0.25 - 171.56)	0.26	34.11 (0.61 - 1920.13)	0.09

*p<0.05

**p<0.1

4.8.11 Odds ratio for ACWR and illness incidence

The associations between the ACWR and illness, as per four week training blocks, was measured with odds ratios (OR) as shown in Table 16. A significant relationship was found for ACWR and illness incidence in weeks 13 to 16 when the ACWR was <0.05 (p= 0.032, OR: 2.11 (1.04 - 4.28)).

Table 16: Odds ratio table for risk factors for illness incidence according to ACWR's.

ACWR		**Week 1 to 4 (Early training)**		**Week 5 to 8 (Mid training)**		**Week 9 to 12 (Pre-race)**		**Week 13 to 16 (Post-race)**	
Reference	**ACWR ratios**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**	**Odds ratio (95% CI)**	**p-value**
>=1.00 - <1.50	≥0.00 - <0.50	1.52 (0.67 - 3.40)	0.31	1.79 (0.78 - 4.12)	0.17	1.29 (0.45 - 3.67)	0.64	2.11 (1.04 - 4.28)	**0.038***
	≥0.50 - <1.00	1.05 (0.55 - 2.00)	0.89	1.01 (0.54 - 1.90)	0.98	1.64 (0.86 - 3.11)	0.13	1.61 (0.82 - 3.15)	0.17
	≥1.00 - <1.50	1.00		1.00		1.00		1.00	
	≥1.50 - <2.00	2.14 (0.55 - 8.28)	0.27	1.79 (0.47 - 6.79)	0.39	1.80 (0.37 - 8.83)	0.47	2.40 (0.78 - 7.33)	0.13
	≥2.00	6.34 (0.12 - 324.66)	0.36	1.29 (0.06 - 27.57)	0.87	8.79 (0.17 - 455.80)	0.28	7.49 (0.14 - 388.78)	0.32

**p<0.05*

4.9 Summary of results

A significant difference was found between the uninjured and injured group with regard to the average number of runs per week (p=0.0286) and average sessional RPE (p=0.0030) over the 16 weeks. No significant differences were found for average distance run or average duration spent running per week between the two groups. No significant differences were found between the healthy and ill groups for any of the above training parameters.

The overall injury incidence was 31% over the 16-week study period. Of the total number of injuries sustained, 56 were new injuries and 15 were recurrent injuries. The average number of training sessions missed due to injury over the 16 weeks was three session. The most commonly injured structure was muscle (37%) and the most common anatomical region injured was the knee (19%). The overall illness incidence was 66% over the 16-week study period. Week 13 and 14 had the highest illness incidence, which correlated to one and two weeks after the ultramarathon event. The average number of training sessions missed due to illness over the 16 weeks was three sessions. Congestion was the main illness-related symptom reported by participants (54%).

A moderate, significant negative correlation was found between average external training load and injury incidence (r=-0.56; p=0.025). As the external training load decreased the injury incidence increased. No correlation was found between average internal training load and injury incidence. No correlations were found between average external training load and average internal training load; and illness incidence respectively.

Significant relationships were found between external training load and injury incidence in weeks 5 to 8 for those who ran less than 30km per week. Significant relationships were found for external training load and illness incidence in weeks 5 to 8, 9 to 12 and 13 to 16 for those who ran less than 30km per week. These findings suggest that running less than 30km per week may increase the risk of injury or illness when training for an ultramarathon event.

Significant relationships were found between the acute:chronic workload ratio (ACWR) and injury incidence in weeks 1 to 4, 5 to 8 and 13 to 16 when the ACWR was >1.5. Significant relationships were found between the ACWR and illness incidence in weeks 13 to 16 when the ACWR was <0.05. Therefore, an ACWR below 0.5 or higher than 1.5, may increase the risk of injury or illness in the following week.

CHAPTER 5: DISCUSSION

The aim of this study was to determine if there are any associations between training loads, injury and illness profiles of ultramarathon runners with the purpose of adding to the current knowledge base regarding the monitoring of training loads and prevention of injury and illness in this population group.

The first section of this discussion will address the generalisability of the results. The second, third and fourth sections will review the findings pertaining to training loads, injury and illness incidences and how this compares to current literature. This discussion will then analyse and critically evaluate the results of our study and discuss possible training load errors that may increase the risk of sustaining a running-related injury and/or illness as well as potential 'safe zones' that may decrease the risk of injury and/or illness. The discussion will focus on the main findings of our study and will follow the order of presentation of the results in *Chapter 4.* Finally, the limitations of the study will be presented and recommendations for future studies will be made.

5.1 Participants

5.1.1 Sample size

One hundred and nineteen participants took part in this study. Upon conclusion of data collection, participants were then stratified according to injury and illness status respectively. Similar studies investigating the relationship between workload and injury in both ultramarathon runners and elite youth football players had sample sizes ranging from 32 to 662 participants (Bowen et al., 2017; Rasmussen et al., 2013). The sample sizes of studies investigating the relationship between training or competition and illness in multiday endurance runners and endurance-based activities in general ranged from 75 to 396 participants (Gleeson et al., 2013; Krabak et al., 2011).

Therefore, while our sample size is in keeping with previous studies in this field of research, it must be noted that a larger sample size would have improved the external validity of the study. The small injured group in comparison to the uninjured group and the small healthy group in comparison to the ill group may have prevented detection of between group differences or may have overestimated the significant effects. Our sample size was just smaller than the 80% confidence level calculated. Therefore, a larger sample size would have increased the power of this study's results.

The time-loss definition of a running-related injury may have also contributed to the small number of participants in the injured group in comparison to the uninjured group. An alternative definition, that would consider injuries of an overuse nature, such as that used in the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire, may have given us a larger injury group and potentially established greater between group differences with reference to training parameters. The illness definition included all medical complaints and therefore was not specific to the number of training sessions missed or the type and amount of illness-related symptoms present. This may have caused an over-reporting of illness and therefore may account for the large illness group.

5.1.2 Participant descriptive characteristics

The average age (41± 9.7 years), stature (174.5 ± 9.4 cm), body mass (71.3 ± 12.6kg) and BMI (23.4 ± 2.3 $kg.m^{-2}$) of participants in this study was similar to other studies in the field of ultramarathon running (Junior et al., 2013; Knobloch et al., 2008; Krabak et al., 2011). Comparing the descriptive characteristics of the uninjured versus injured group, no significant differences were found for age, stature, body mass or BMI. These similarities in participant descriptive characteristics allow for effective between group comparisons. A significant difference was found for age between the ill and healthy group. Participants in the ill group were on average six years younger than those in the healthy group. No research thus far has investigated the influence of age on illness incidence therefore it is possible that this may affect between group analysis of the healthy and ill group.

No significant differences were found for any of the above training parameters (distance, duration, frequency and sessional RPE) between the ill and healthy groups. While the ill group was found to be significantly younger, these parameters do not appear to influence the risk of illness or explain the difference in age between the two groups. Other factors such as the duration or intensity of cross-training sessions, poor nutrition and sleep may account for differences between the ill and healthy group (Schwellnus et al., 2016). The investigation of these potential contributing factors and the effect of age on illness risk were beyond the scope of our study. More research is thus required in this field.

No significant differences were found between the injured and uninjured group and the healthy and ill group with reference to baseline training parameters. These include average weekly distance, average weekly duration, average weekly frequency and average weekly sessional RPE. This allows for effective between-study comparisons of training-load parameters and injury and illness.

There are many other factors that should be taken into account when comparing the two groups. Most participants in this study had been running for more than 10 years and 72% of participants had previously participated in an ultramarathon event. Greater experience has been associated with a greater training base and therefore potentially a higher injury threshold (Nielsen et al., 2012). This may explain the relatively low injury incidence proportion in comparison to other studies. Also, runners who are more prone to injury may never get as far as running a single ultramarathon let alone multiple.

As this dissertation was focused on ultramarathon runners specifically, running-related training load was the primary outcome documented during data collection. The effect of cross-training, nutrition, sleep and recovery is therefore not known. The above factors may act as confounding variables, making between group comparisons of the injured and uninjured groups and the ill and healthy groups difficult. However, this is beyond the scope of this dissertation.

5.2 Injury and Illness profiles

5.2.1 Injury Profiles

A total of 37 participants among the 119 participants sustained a running-related injury over the sixteen week study time period, indicating an incidence proportion of 31%. The overall injury incidence was 5 per 1000 hours of training. We used the 2015 consensus statement which identified running-related injuries through a modified Delphi approach. A running-related injury was classified according to time-loss (three or more missed training sessions). According to Clarsen and Bahr (2014), the 'time-loss' definition of an injury is both reliable and easy to use amongst coaches and athletes and therefore does not require the expertise of a healthcare professional. However, this definition also has several limitations. Many injuries may be missed as athletes often continue to train despite having an injury. Often these injuries are not 'serious' enough to warrant stopping training but rather managed through load modification such as reducing the length or intensity of the exercise session and/or through the use of certain over the counter medications (Clarsen & Bahr, 2014). The use of over the counter medications has been previously identified by Thorpe (2018) for masking injury and illness related symptoms.

With regard to the definition of a running-related injury as proposed by Yamato et al. (2015), had we defined injury differently our injury incidence may have been higher. This may have led to more significant findings between training loads and injury incidence. However, the injury proportion and incidence found in our study is still in keeping with other studies with reference to running-related injuries (Taunton et al., 2002; van der Worp et al., 2015).

The wide range in incidence rate in current literature can largely be attested to differences in the definitions of a running-related injury as mentioned above as well as the sample size and different sporting populations studied (Taunton et al., 2002; van der Worp et al., 2015; Van Middelkoop et al., 2007).

Another possible reason for the low injury incidence reported in our study is due to the lack of overuse injury data used. Most running-related injuries are not acute (i.e. muscle strains) but overuse in nature. Overuse injuries are generally the result of a mismatch between training load and load tolerance (van der Worp et al., 2015). Saragiotto et al. (2014), described overuse injuries as injuries with a gradual onset due to repetitive microtrauma as opposed to a single inciting event. Tendons are therefore particularly at risk of becoming injured due to their slow adaptability to the imposed load (van der Worp et al., 2015). Variations in our findings and other studies could be due to the self-reporting nature of injuries and our definition of a running-related injury. This method of measurement versus the 'actual' injury diagnosis by a health professional may have reduced the internal validity of these findings. However, this would be timely and expensive for participants and so the former method of injury reporting was chosen.

In this study, the anatomical area most commonly injured was the knee (19%), followed by the foot, hip, ankle and hamstring. Results from this study are consistent with many other studies which have reported the lower limb to be the most commonly injured area of the body, more specifically the knee (Kluitenberg et al., 2015; van der Worp et al., 2015; Van Middelkoop et al., 2007). According to Taunton et al. (2002), the knee was the most common site of pain followed by the foot and ankle. This is also supported by Lopes et al., (2012), who reported the knee to be the most common structure injured in both ultramarathon and non-ultramarathon runners.

Imbalances in the lower limb may contribute to the development of running-related injuries (Ferber, Hreljac, & Kendall, 2009). The hip serves as a dynamic stabiliser of the lower limb. Weakness of the hip stabilisers, such as the hip abductors and hip external rotators, has been found in patients with patellofemoral pain syndrome and iliotibial band friction syndrome (Ferber et al., 2009). Weak hip abductors increases the amount of adduction occurring at the hip which increases the angle of pull on the knee (Ferber et al., 2009).

This is supported by Ramskov et al. (2015) who found greater hip abductor strength to be associated with less patellofemoral pain (Molloy, 2016). Other biomechanical abnormalities that have been associated with an increased risk of knee pain include knee malalignment, excessive pronation and an increased Q-angle (Molloy, 2016; Taunton et al., 2002).

Due to the repetitive stress that the knee is subjected to whilst running, especially with an increase in distance, it is no surprise that it is the most commonly injured anatomical region in runners (Hreljac & Ferber, 2006). Ferber, Hreljac and Kendall (2009), stated that the knee accounts for up to 50% of overuse injuries found in runners with patellofemoral pain syndrome, also known as 'runners knee', being the most common condition. Iliotibial band friction syndrome, patella tendinitis, plantarfasciitis and Achilles tendinopathy are among other common running-related injuries (Ferber et al., 2009; Taunton et al., 2002).

Our study is unique in that it specifically looks at the injury pattern preceding an ultramarathon event as well as the injury pattern that occurs post an event. This allows us to add to current literature in terms of the type of structure and anatomical region most commonly injured in ultramarathon runners in preparation for and subsequent to an ultramarathon event.

5.2.2 Illness Profiles

The illness incidence proportion over the 16 week study period was 66%. This is very high in comparison to a study conducted by Schwellnus et al. (2016), who reported an illness incidence proportion of 6% to 17%. However, their study was over a shorter time period compared to our study and occurred during international games or tournaments as opposed to over a 16 week period. Other research has reported illness incidences specifically during an ultramarathon event which therefore makes it difficult to compare to our study (Schwabe, Schwellnus, Derman, Swanevelder, & Jordaan, 2014).

The overall illness incidence in our study was 16 per 1000 training days. Schwabe et al (2014), reported an illness incidence of 12.98 per 1000 runners during a 56km ultramarathon event. This is the same ultramarathon that was used in our research study and therefore allows for between study comparisons as the type of training and stress endured by the athletes is likely to be of a similar nature. However, as illness incidence is reported per 1000 training days in our study and per 1000 runners in their study, again comparisons are limited.

In a multiday ultramarathon event, injuries and illnesses were minor in nature with only 7.5% accounting for medical-related illnesses (Krabak et al., 2011). This is lower than the illness incidence reported in our study and could be accounted for due to the differences in illness definitions, as well as the differing time periods for data collection. It could also be related to the fact that people who were ill at the time of the multiday ultramarathon event would not have run on this day which would inherently reduce the illness incidence. It is evident that defining illness correctly is important in future studies in order to establish an accurate illness incidence report. This will add to current literature which is somewhat limited as well as allow for effective between study comparisons.

The main illness-related symptom reported over this study's sixteen week time period was congestion (54%). In a longitudinal study designed by Hoffman and Krishnan (2014), they found allergies and exercise-induced asthma to be the most common illness-related symptoms. Schwellnus et al. (2016) found that 50% of illnesses reported by athlete's effect the respiratory tract. This is most commonly thought to be caused by an infection; however, it may also be due to allergies or inflammation. Symptoms of an upper respiratory tract infection include a sore throat, congestion and cough (Schwellnus et al., 2016). This aligns with the findings of our study with congestion being the main illness-related symptom. Possibly congestion as a symptom alone is too broad. More specific illness-related symptoms may have helped further explain the high illness incidence.

Over a five-year period Nieman (2009) observed key immunological changes in participants taking part in the 160km Western States Endurance Run. Twenty-four percent of the participants reported an URTI in the one- to two-week period following the ultramarathon event. Following an acute bout of stress (i.e. an ultramarathon), the immune system is believed to be suppressed (Walsh et al., 2011). It is during this period of decreased immunity that the risk of sustaining an URTI increases. Salivary immunoglobulin A (IgA) is thought to serve as the first line of defence against pathogens entering through the mouth. During periods of prolonged and high intensity exercise, IgA synthesis decreases (Walsh et al., 2011). A relationship between impaired salivary IgA secretion and URTI's has been found (Walsh et al., 2011). The high illness incidence found in our study highlights the strong effect of prolonged, high intensity exercise on immune system function mentioned above. The spike in illness incidence in week 13 and 14, one to two weeks following the Two Oceans ultramarathon event reiterates the increased risk of illness following an acute bout of stress.

The average number of training sessions missed due to illness (time-loss) was 3 ± 1. This is low in comparison to the high illness incidence found in our study. This implies that despite runners developing illness-related symptoms, they were still able to train through these periods of stress.

This is supported by Fricker et al. (2005), who examined the influence of training loads on patterns of illness in elite distance athletes.

They reported that runners who were ill appeared to decrease their training load so that they could continue to train during times of illness. Another possibility is that runners may have shifted their training days around their illness so that they still completed all of their scheduled training sessions but on different days of the week. They may have also reduced their training load with shorter and lower intensity training sessions to accommodate for their illness.

Despite this, training with a possible underlying systemic infection can negatively affect a variety of organ systems (Schwellnus et al., 2016). This includes the musculoskeletal system leading to muscle wasting, decreased co-ordination and muscle strength; the cardiovascular system causing a decrease in oxygen consumption and therefore decreased endurance capacity and changes in the metabolic system (Schwellnus et al., 2016). Furthermore, exercising with a fever can affect the body's ability to regulate body temperature resulting in increased fluid losses. Exercising with an acute infection can cause serious medical complications and even death (Schwellnus et al., 2016). This is especially true if exercise is rigorous or places the body under extreme stress such as experienced during prolonged periods of high intensity training (Schwellnus et al., 2016).

Due to the high illness incidence reported in our study and the low number of training sessions missed, it may be beneficial to educate athletes on the negative effects of exercising with an underlying systemic infection.

In the future, signs and symptoms that may indicate possible infection could be useful for athletes in terms of monitoring their response to the imposed load. This could help athletes determine when rest and recovery may be needed.

5.3 Training parameters over the 16 weeks

5.3.1 Injured versus uninjured group

No significant difference was found between the injured and uninjured group with regard to average weekly training volume (distance) and average weekly duration over the sixteen week period. While no significant difference in average training distance was found, the uninjured group ran on average approximately 10km more per week than the injured group. This may indicate that higher training mileages are associated with lower injury risk (Gabbett, 2016). This is supported by Jones et al. (2017), who proposed that a higher chronic workload overall may be a protective factor against injury. This could be related to the experience of the runner, with more experienced runners potentially having a higher injury threshold due to a greater training base. This allows them to withstand greater weekly training mileages (Nielsen et al., 2012).

The insignificant finding in training volume may be due to the relatively small sample size of the injured group (37 participants) in comparison to the uninjured group (82 participants). Had we had a larger sample size as mentioned in section 5.1.1 above, the findings may have been different. A significant difference was found for external training load and injury between the injured and uninjured groups in weeks 5 to 8 (mid training block) for participants who ran less than 30km per week in comparison to those who ran 30km to 60km per week. This is similar to the results reported by Rasmussen, Nielsen, Juul and Rasmussen (2013), who found that running less than 30km per week increased one's risk of injury in comparison to those who ran 30km to 60km per week in preparation for a marathon. Their recommendations were therefore to run more than 30km per week in training for a marathon.

Other possible predisposing factors may include younger age, previous injury and not having previously run a marathon (Rasmussen et al., 2013). Less than 30% of our participants said that the Two Oceans Ultramarathon race would be their first Ultramarathon. The remainder of our study population had run on average ten ultramarathons prior to the start of this study indicating a relatively high level of experience. Experience is thought to be associated with a decreased risk of injury and therefore may contribute to the low injury incidence found (Kluitenberg et al., 2015; Nielsen et al., 2012; Taunton et al., 2002). This is also highlighted by the insignificant findings in our study with reference to endurance running experience between the two groups.

A significant difference was found between the injured and uninjured groups with regard to running frequency per week ($p=0.0286$). Gabbett (2016) reported that a low frequency of running was associated with a higher risk of injury. He hypothesised that this relationship was as a result of the athlete not being adequately conditioned to the specific demands of the sport. In the systematic review conducted by Nielsen et al. (2012), a running frequency of six to seven times per week was found to increase the potential risk of injury. They proposed an ideal frequency of two to five runs per week. While this is in keeping with the results of our study, the injured group ran one less time per week in comparison to the uninjured group (three versus four runs, respectively). This may indicate that the injured group was not prepared or conditioned enough for the task at hand which is in support of Gabbett's findings discussed above (Gabbett, 2016).

A significant difference was found between the two groups in training intensity (RPE) over the sixteen week period (p=0.0030). The uninjured groups RPE was higher than the injured groups RPE, 5 and 4 respectively. According to Nielsen et al. (2012), literature is contradictory with regard to training intensity and injury. Lambert et al (2008), reported an increased risk of fatigue and overtraining with too frequent periods of high intensity training. They also found a common mistake amongst distance runners of training at too high an intensity with resulting compromises in performance. Nielsen et al. (2012) recognised that most studies report intensity as a subjective measure of speed or pace. Subjective reporting of pace may be inaccurate and therefore quasi-objective reporting of intensity was recommended, such as in our study, with the use of the RPE scale (Nielsen et al., 2012). The validity and reliability of the RPE scale in measuring exercise intensity has already been established (Foster et al., 2001; Herman et al., 2006).

Given the nature of our longitudinal study design and continued training load monitoring after injury occurrence, an injury sustained during the study time period would have likely lead to a decrease in training load in the following week as a consequence of the injury. This may explain the insignificant finding in training distance overall between the injured and uninjured group.

5.3.1.1 Internal training load (duration X RPE) and injury incidence

No association between internal training load (RPE X duration) and injury was found. In a systematic review, no difference in injury incidence was found between two groups when one increased their duration by 10% per week over a thirteen week period and the other increased their duration by 24% over an eight week period (Nielsen et al., 2012). Looking at injury incidence per exposure time (i.e. 1000 hours running) it has been found to be a better predictor of injury than mileage alone. Bovans et al. (1989) as cited in Nielsen et al. (2012), found that injury incidence decreased as time spent running (duration) increased. This may also be explained by the experience of the runner. Increasing one's intensity (i.e. speed of running) was associated with an increased risk of injury. However, it may be that increasing one's speed is associated with certain types of running-related injuries such as iliotibial band friction syndrome and Achilles tendinitis (tendinopathy) as opposed to injuries in general. This is especially true if total weekly mileage is accounted for (Nielsen et al., 2012).

While no significant difference was found between the injured and uninjured groups in internal training load, a significant main effect of time was found (p=0.00001).

Internal training loads were significantly higher in week 12 compared to weeks 1, 2, 4, 5, 10, 11 and 13 to 16 ($p<0.05$); and significantly lower in week 13 compared to weeks 3, 7 to 9 and 12 ($p<0.05$). This is somewhat to be expected as the Ultramarathon event took place in week 12 and therefore ties in with the high internal training loads found in this week. As week 13 is one week post event, one would also expect a significant drop in the internal training load in this week as athletes start to recover.

Drew and Finch (2016) evaluated the relationship between training load and injury, illness and soreness. They found a sudden spike in week to week internal loads to be a very good predictive marker for injury and illness and thus the use of internal training loads is still recommended to be used in the monitoring of an athlete's training load.

5.3.1.2 External training load (distance) and injury incidence

No significant differences were found between the injured and uninjured groups' external training load. However, a significant main effect of time was found ($p=0.00001$). External training loads were significantly higher in week 12 compared to weeks 13 to 16 ($p<0.05$); and significantly lower in week 13 compared to weeks 2 to 10, 13, 14 and 16 ($p<0.05$) respectively. As mentioned above, week 12 is when race day occurred which explains the high external training loads found in this week.

A significant negative association was found between external training load and injury ($r=-0.56$; $p=0.025$). As the external training load decreased the incidence of injury increased. Gabbett (2016) found that increasing one's overall training load improves performance. In individual sports such as running, an association between higher chronic training loads and improved performance has been established (Gabbett, 2010). This ties in with the findings in our study in that a significant difference was found between the injured and uninjured groups with regard to four weekly running distances and injury incidence. Therefore this substantiates the association proposed by Gabbett (2010) above.

While many studies have found higher training volumes to be associated with improvements in performance and potentially a protective factor against injury, it has also been associated with higher rates of injury and illness (Gabbett, 2016). Walter et al. (1988) and Macera et al. (1989) both found that running more than 64 $km.week^{-1}$ was associated with an increased risk of injury (Nielsen et al., 2012).

Studies conducted by Marti et al. (1988), Jacobs et al. (1986) and Kaplan et al. (1982) investigating differences between an injured and uninjured group found that the injured group ran more miles per week (Nielsen et al., 2012). This suggests that a greater mileage is associated with an increased risk of injury.

When comparing our results with the results of Walter et al. (1988), and Macera et al. (1989), there is potentially an explanation for the seemingly contradictory findings. A weekly mileage of 64 $km.wk^{-1}$ represents a high weekly mileage. Therefore increased external load could be protective of injury up until a certain point. These findings could imply a potential threshold at which increased external training load changes from being a protective factor against injury to a predisposing factor to injury. Overtraining and undertraining may have many negative effects on an athlete and their performance such as injury, illness, fatigue and exercise-induced muscle damage (Drew & Finch, 2016; Jones et al., 2017).

Consequently, it is of paramount importance that athletes are both physically and mentally prepared for the task at hand. Gabbett and Whiteley (2017) have suggested that if an athlete is loaded beyond the specific requirements of an event or match (i.e. by increasing their overall chronic load) then their risk can be minimised during these high periods of stress and in turn increase an athlete's injury threshold. Many studies have suggested the '10% rule' which recommends increasing one's weekly mileage by no more than 10% per week to minimise the risk of injury or illness in the following week (Nielsen et al., 2012). While this has been found to be effective, it may be less important in experienced athletes with a greater training base (Nielsen et al., 2012).

5.3.2 Ill versus healthy group

No significant differences were found between the two groups for average weekly distance, average duration, average frequency and average sessional RPE. Fricker et al. (2005) examined a group of runners and their training and illness profiles over a period of four months. They found that those who remained healthy had a greater weekly training volume (distance) than those who were ill. However, those who sustained an illness had trained at a higher intensity (RPE). While the study conducted by Fricker et al. (2005), is comparable to ours as they also looked at distance runners over the same study time period, their sample size was much smaller than ours (20 versus 119 participants, respectively). Their significant findings may be negated in a larger study population. Also, their participants were not training for an ultramarathon event.

The physiological stress experienced by distance runners in preparation for an ultramarathon may be different to the stress experienced by runners in their off-season period. This may account for differences in weekly mileage and illness incidence.

Mårtensson, Nordebo and Malm (2014) also reported higher incidences of illness with increased training intensities. Despite this, illness appears to have little effect on an athlete's ability to train. This is supported by our study in that time-loss due to illness was small in comparison to the high illness incidence reported. Fricker et al. (2005), found no significant differences in physiological measures of performance between a healthy and ill group. This may indicate that runners with an illness adapted their training load by decreasing their weekly mileage so that they could still train through periods of stress or illness. To date, no studies have reported on training illness and frequency specifically and therefore between study comparisons are limited.

A significant relationship was found for external training load (distance) and illness incidence between the ill and healthy group in weeks 5 to 8 (mid training block) (p=0.0176), 9 to 12 (pre-race) (p=0.0067) and 13 to 16 (post-race) (p=0.0001) for participants who ran less than 30km per week in comparison to those who ran 30km to 60km per week. Undertraining (running less than 30km per week) may increase an athlete's risk of illness as the body has not adapted to the physiological stress of the imposed load. Currently, there is limited data on training parameters and illness incidence in ultramarathon runners. More research is needed in this field to allow for effective between study comparisons.

5.3.2.1 Internal load (duration X RPE) and illness incidence

A significant difference was found between the ill and healthy groups in internal training load (p=0.034). The healthy group's internal training load was significantly higher than the ill group's internal training load. A higher internal training load may serve as a protective factor against illness. A significant main effect of time was also found between the two groups (p=0.00001) with week 12 being significantly higher than all other weeks. This correlates with the Two Oceans Ultramarathon event.

No association between internal load and illness was found in this study. This is supported by Drew and Finch (2016), who found no relationship between internal load and illness in elite runners. In contrast to this, Hellard et al. (2015), found a significant relationship between the two.

Hellard et al.'s (2015) study was considered of highest quality in the systematic review by Drew and Finch (2016). However, their sample size was small (28 participants) and was based on elite swimmers as opposed to ultramarathon runners. Comparison between the two studies is therefore limited.

The differences in findings may also be related to the way in which the internal load was measured. Foster et al. (2001) defined the internal load as a product of duration times RPE according to a 10 point scale. The same method was applied in our study. However, Fricker et al. (2005) determined internal load according to a five point scale and Hellard et al. (2015) defined internal load as intensity according to lactate accumulation times by duration. This highlights the difficulty in making between study comparisons.

5.3.2.2 External load (distance) and illness incidence

No significant difference was found between the healthy and ill groups in external training load. However, a significant main effect of time was found (p=0.000001). External training loads were significantly higher in week 12 and significantly lower in week 13, one week after the ultramarathon event.

No association was found between external training load and illness. Currently, literature exploring the relationship between external training load and illness is inconsistent. In a systematic review of the literature by Drew and Finch (2016), six studies found an association between external training load and illness, whilst two studies found no relationship. Of the two studies, one looked at elite runners specifically and found no relationship between internal and external training load and illness (Fricker et al., 2005).

It is difficult to compare our findings to other studies as most studies investigating the relationship between external training loads and illness are in other sports such as cricket, swimming and soccer and not ultramarathon running explicitly. As a result, our study contributes to the current knowledge base on ultramarathon runners and external training loads and illness incidence.

It is important to recognise that while internal and external training loads decreased as injury incidence increased, if the injury occurred in the same week as the data being collected then a lower training load will be reported. This may give the impression that a lower training load was causative of injury as opposed to being secondary to injury. This is a methodological flaw in our study and may increase the risk of a type 2 error.

Drew and Finch (2016) noted that if an injury or illness occurs in the same week of data collection then a low training load will be recorded. Therefore, the illness or injury leads to a reduced training load rather than the reduced training loads leading to injury. Thus, they recommend collecting data over a rolling seven day period to account for this discrepancy (Drew & Finch, 2016).

5.4 The ACWR and injury and illness

A significant difference was found between the injured and uninjured group's ACWR in week 10. The uninjured group's ACWR (0.96) was significantly higher than the injured group's ACWR (0.72). According to the reference value used in this study (≥1.00 - <1.50) both groups are below this reference value which may indicate an increased risk of injury in the following week. An ACWR of 0.8 to 1.3 has been recommended as the 'sweet spot' in training load prescription, above and below which the relative risk of injury increases (Gabbett, 2016). However, this is not specific to ultramarathon running.

While the uninjured group's ACWR is within the 'safe' zone according to Gabbett (2016), the injured group's ACWR is below this range. This may indicate an increased risk of injury. Therefore, a higher chronic workload overall may be protective of injury.

A significant difference was found between the ill and healthy group's ACWR in week 3, 6-9, 11-13, 15 and 16. The ill group's ACWR was significantly higher than the healthy group's ACWR in all the above weeks (Table 10). While the ill group's ACWR fell within the proposed 'sweet spot' for training load prescription (Gabbett, 2016), the healthy group's ACWR fell below this range. This is contradictory to the findings above as here a lower chronic workload appears to be protective of illness. Limited research exists on the use of the ACWR and predicting illness incidence in the following week, thus more research is needed.

A significant relationship was found when examining the ACWR and illness incidence over a four week training period. This was in weeks 13 to 16 when the ACWR was <0.50 in comparison to the reference value (≥1.00 to <1.50). These findings indicate that a lower training mileage was associated with an increased risk of illness. However, weeks 13 to 16 are after the ultramarathon event took place. Thus, these more likely highlight that participating in an ultramarathon increases the risk of illness post event as opposed to a low training mileage being associated with an increased illness incidence.

An athlete's mileage is expected to decrease following completion of an ultramarathon as they move into recovery mode. Establishing a balance between exercise and recovery is important to allow for physiological adaptations to occur as well as minimise the risk of injury and illness (Bowen et al., 2017; Gabbett, 2016). The ACWR and risk of illness in the following week have not previously been reported therefore, comparisons to other studies are impossible. Consequently, these findings contribute to the limited epidemiological data on training loads and illness thus far.

Significant relationships were found upon examination of the ACWR and relative injury risk. When the ACWR was ≥1.5 to <2.00 a significant relationship was found in weeks 1 to 4 and weeks 13 to 16 ($p=0.0001$ and $p=0.03$ respectively). When the ACWR was ≥2.00 in weeks 5 to 8 a significant relationship was also found ($p=0.03$). An ACWR of >1.5 is suggestive of a sudden 'spike' in an athlete's training load (Gabbett, 2016). It is at this point that the risk of injury in the following week starts to rise. This is in keeping with the findings in our study.

In a study reviewing fast bowlers in cricket, when the ACWR was >1.5 the risk of injury was two to four times greater in the subsequent week. Unfortunately, research thus far is not specific to runners or ultramarathon runners. Training loads should be specific to the sport in question as this may influence the type of injury sustained as well as specific to the athlete being monitored as each individual responds differently to the same pattern of loading. The same external load applied can have differing internal loads on different days depending on the athlete's current state of fatigue. It is therefore, important that this is constantly monitored. Gabbett (2016) found that 40% of injuries in football players were the result of a sudden spike in an athlete's training load in comparison to the previous week. This was also found in rugby players with large changes in their weekly training load (Gabbett, 2016). Preventing these errors in training may then decrease the risk of sustaining an injury or illness.

The use of the ACWR to monitor these sudden spikes in training load as well as determine the athlete's overall chronic load on a four weekly basis has proven to be effective (Williams et al., 2017). Both rolling averages and the exponentially weighted moving average have been used in the calculation of the ACWR. The EWMA method of calculation gives more weighting to recent training loads towards the end of a four week training block and lesser weighting to older values. It appears to be more sensitive to changes in the chronic load as well as predicting signs of fatigue. It is therefore, recommended in the calculation of the ACWR (Williams et al., 2017). Until such time as results are established for ultramarathon runners specifically, an ACWR of 0.8 to 1.3 and not exceeding 1.5, appears to be safe in terms of minimising the risk of injury or illness in the following week (Blanch & Gabbett, 2016; Gabbett, 2016).

Current literature suggests the use of both the absolute workload (internal and external workload) as well as the relative workload (ACWR) in determining how 'fit' or 'prepared' an athlete is. Measuring both the internal and external training load tells us about the physiological and psychological stress imposed on the athlete. This gives coaches and athletes a better picture of an athlete's response to the load implied (Blanch & Gabbett, 2016; Bourdon et al., 2017).

While excessive loading in one week can increase the risk of injury in the following week, small chronic workloads overall can also increase the risk of injury (Blanch & Gabbett, 2016). Recent literature suggests that higher training loads are protective against injury. The idea is that higher chronic loads overall help to better prepare the athlete for the task at hand. These high loads allow physiological adaptations to occur which enable athletes to tolerate greater loads (Bourdon et al., 2017). This increased load tolerance potentially increases an athlete's injury threshold and therefore would result in improved performance. The same can be said about undertraining. Undertraining can also increase the relative risk of injury as the athlete is not conditioned enough to the imposed load (Bourdon et al., 2017).

The results from our study add to the current knowledge-base on the use of the ACWR in ultramarathon runners specifically. For individual athletes, an ACWR of 0.5 to 1.5, using the EWMA method of calculation, may be appropriate in terms of minimising the risk of injury or illness in the following week until such time as more research is established. Continuous monitoring of an athlete's training load with respect to internal loads, external loads and the ACWR is proposed as well as the flexibility of coaches and athletes to adapt their training programmes if the athlete is not responding appropriately.

5.5 Limitations of the study and recommendations for future research

There were several limitations identified in this study. While the sample size was comparable to various other studies, a larger sample size would have allowed for greater statistical power and external validity.

Due to variations in running-related injury and illness definitions, incidence proportions may be over or under-reported and between group differences may have been masked. A more standardised approach in terms of defining a running-related injury or illness may prove to be beneficial across all future running-related studies.

Another limitation was the retrospective nature of the baseline questionnaire. This may have led to recall bias. This was accounted for by ensuring definitions were clearly explained and that the questions were easy to comprehend.

The methodological reporting of training, injury and illness may too have served as a limitation to this study. As the data was collected longitudinally from week to week, an injury or illness reported in one week may have influenced the training volume completed in the week of the illness or injury. This could also have impacted training volumes in subsequent weeks if the injury or illness persisted beyond the week of reporting. Therefore, due to our data collection protocol, reductions in training volume may not necessarily have predisposed to injury or illness but rather have been as a consequence of injury or illness. This measurement bias could be corrected in future research by monitoring participant training volume up until the point of injury or illness and then analysing their training load in the build-up to that point. However, this was not the purpose of our study. Otherwise, retrospective analyses could be performed on training data preceding injury incidence across a sample population and analysed to ascertain the influence of training volume on injury and illness development.

The self-reported nature of the training data collected in this study could also act as a limitation, in that participants may have over or under-reported their training load. This could either have been due to a misunderstanding of the research question or due to participant response bias. To increase objectivity, direct integration of participants training data from smart watches could be investigated in future studies. This would help decrease capturing errors in training data.

Similarly, the subjective self-reporting of injury-type was a limitation in this study. Injury-types reported by the participants were not validated using any diagnostic imaging or medical expert review. Therefore this could have negatively influenced the internal validity of the study's findings. Future research could improve internal validity by specifically using the OSTRC questionnaire to monitor injuries. This questionnaire does not require professional assessment for the monitoring or diagnosis of injuries and accounts for reduction in training loads without the time-loss requirement. This may be a better way of assessing injuries in runners and ultramarathon runners rather than the definition used in this study.

Due to the relatively small sample size in comparison to the total amount of Two Oceans Ultramarathon entrants, a follow-up study with a larger population would be beneficial. This would possibly better help to identify if there are between group differences between an injured and uninjured group and an ill and healthy group with respect to training load parameters.

As no literature exists thus far that is specific to ultramarathon runners with regard to the ACWR reference value, future research is needed in this field.

CHAPTER 6: SUMMARY AND CONCLUSION

Running-related musculoskeletal injuries and illness are two established negative effects of running. Despite the growing research in the field of running and ultramarathon running, the incidence of running-related injuries and illness is still high (Kluitenberg et al., 2015; Schwellnus et al., 2016). Training errors are thought to account for many running-related injuries and illness and thus can be prevented (Nielsen et al., 2012). Therefore, the monitoring of training loads has become important in terms of minimising the risk of injury and illness. Understanding the relationship between all three factors may guide coaches and athletes in the development of future training programmes. This study is one of few to assess the relationship between injury, illness and training load parameters and therefore contributes to the body of knowledge on the influence of training load on injury and illness in ultramarathon runners. This is particularly the case with regard to illness as research in this area is limited.

The aim of this study was to determine if a greater training load increases the risk of injury and illness in ultramarathon runners. Based on the findings in this thesis the study objectives may be answered as follows:

> *To describe the incidence rate of overall and region-specific running-related injuries in a population of ultramarathon runners in the 16 week period surrounding an ultramarathon event.*

The overall injury incidence proportion was 31% with week 13 reporting the highest weekly injury incidence of 7%. This is one week post the Two Oceans Ultramarathon race. The overall injury incidence was 5 per 1000 hours of training. Soft tissue injuries accounted for 71% of the injuries with 37% occurring in muscles and 22% in tendons. The most commonly reported anatomical region injured was the knee (19%) followed by the foot (14%). Overall, the average time-loss due to injury was 3 ± 2 training sessions missed.

> *To describe the incidence rate of illness and illness-related symptoms in a population of ultramarathon runners in the 16 week period surrounding an ultramarathon event.*

The overall illness incidence proportion was 66% with week 13 having the highest illness incidence of 22.45%. This is one week post the Two Oceans Ultramarathon race. The overall illness incidence was 16 per 1000 training days. Congestion was the most common illness-related symptom (54%) followed by fatigue (20%). The average time loss due to illness was 3 ± 1.

To describe the weekly and cumulative training parameters (training volume, training frequency, training intensity, training duration) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.

The mean weekly mileage (distance) was 54.18 ± 31.22 $km.wk^{-1}$ in the uninjured group and 44.32 ± 21.67 $km.wk^{-1}$ in the injured group. The mean weekly running duration was 125.8 ± 83.34 $min.wk^{-1}$ in the uninjured group and 128.1 ± 88.06 $min.wk^{-1}$ in the injured group. The mean training frequency was 4 runs per week in the uninjured group and 3 runs per week in the injured group. The mean training intensity (RPE) was 5 in the uninjured group and 4 in the injured group.

The mean weekly mileage was 51.91 ± 22.04 $km.wk^{-1}$ in the healthy group and 50.79 ± 31.30 $km.wk^{-1}$ in the ill group. The mean weekly running duration was 110.9 ± 70.68 $min.wk^{-1}$ in the healthy group and 132.7 ± 89.00 $min.wk^{-1}$ in the ill group. The mean training frequency was 4 runs per week in the healthy group and 4 runs per week in the ill group. The mean training intensity (RPE) was 4 in the healthy group and 4 in the ill group.

To describe the weekly and cumulative absolute training load parameters (internal load, external load) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.

Week 12 had the highest internal training load of 1384 ± 1086.8 exertional units in the injured group and 1227 ± 1033.8 exertional units in the uninjured group. Week 12 corresponds with the Two Oceans ultramarathon race. The injured group’s average internal training load over the 16 weeks was 564 ± 732.7 exertional units and the uninjured group’s average internal training load over the 16 weeks was 666 ± 745.7 exertional units.

The injured group's average external training load over the 16 weeks was 44.5 ± 30.9 $km.wk^{-1}$ and the uninjured group's external training load over the 16 weeks was 55.7 ± 40.7 $km.wk^{-1}$.The ill group's average internal training load over the 16 weeks was 663 ± 786.6 exertional units and the healthy group's average internal training load over the 16 weeks was 533 ± 554.8 exertional units. The ill group's average external training load over the 16 weeks was 52.1 ± 40.7 $km.wk^{-1}$ and the healthy group's average external training load over the 16 weeks was 52.4 ± 28.2 $km.wk^{-1}$.

To describe the weekly relative training load parameters (ACWR) of the injured and uninjured groups and the ill and healthy groups over the 16 week period.

A significant difference was found between the uninjured and injured groups ACWR in week 10 (p=0.01). The injured group's ACWR was significantly lower in week 10 in comparison to the uninjured group's ACWR. A significant difference was found between the ill and healthy groups ACWR in week 3 (p=0.03), 6-9 (p<0.001; p=0.05; p=0.01; p=0.01), 11-13 (p<0.001; p=0.002; p=0.0002), 15 (p=0.0001) and 16 (p<0.0001). The ill group's weekly ACWR was significantly higher than the healthy groups weekly ACWR in all the above weeks.

To determine whether there are any significant differences between the injured and uninjured groups and the ill and healthy groups with regard to: a) mean training parameters; b) mean internal training load; and c) mean external training load, over the 16 week period.

a) No significant differences were found between the injured and uninjured groups in average weekly distance and average weekly duration spent running.

A significant difference was found between the injured and uninjured groups in average weekly frequency ($sessions.wk^{-1}$) (p=0.0286) and average weekly sessional RPE (0 - 10) (p=0030).

No significant difference was found between the healthy and ill groups in average weekly distance, average weekly duration, average weekly frequency or average weekly sessional RPE.

b) There were no significant differences in internal training load between the injured and uninjured groups. However, there was a significant main effect of time (p=0.00001).

Internal training loads were significantly higher in week 12 compared to weeks 1, 2, 4, 5, 10, 11 and 13 to 16 ($p<0.05$); and significantly lower in week 13 compared to weeks 3, 7 to 9 and 12 ($p<0.05$) respectively.

A significant main group effect in internal training loads was found between the ill and healthy groups ($p=0.034$). Internal training loads were significantly higher in the healthy group in week 12 compared to all other weeks ($p<0.05$). A significant main effect of time was also found between the two groups ($F_{(15,1755)}$ =15,7; $p=0.00001$). Internal training loads were significantly different in week 8 compared to weeks 1, 2 10 to 13, 15 and 16 ($p<0.05$); in week 9 compared to week 1, 2, 10 to 13, 15, 16 ($p<0.05$); in week 11 compared to week 3, 6 to 9, 12 ($p<0.05$); in week 12 compared to all others weeks ($p<0.05$) and in week 13 compared to week 3 to 9 and 12 ($p<0.01$).

c) There were no significant differences in external training load between the injured and uninjured groups. However, there was a significant main effect of time ($p=0.00001$). External training loads were significantly higher in week 12 compared to weeks 13 to 16 ($p<0.05$); and significantly lower in week 13 compared to weeks 2 to 10, 13, 14 and 16 ($p<0.05$) respectively. There were no significant differences in external training load between the ill and healthy groups. However, there was a significant main effect of time ($F_{(15, 1035)}$ =5.7; $p=0.000001$). External training loads were significantly higher in week 12 compared to weeks 1 to 4, 11, 13 to 16 ($p<0.05$); and significantly lower in week 13 compared to week 1 to 14 and week 16 ($p<0.05$).

To identify any significant associations between: a) absolute training load (internal training load; external training load) and injury and illness incidence; and b) relative training load (ACWR) and injury and illness incidence over the 16 week period.

a) There were no significant associations between average weekly internal training load and injury incidence proportions. However, there was a significant negative association between average weekly external training load and injury incidence proportions ($r=-0.56$; $p=0.025$).

No significant associations were found between average weekly internal and external training load and illness incidence proportions.

A significant relationship was also found in weeks 5 to 8 between external training load (distance) and injury incidence when the weekly training load was less than 30km per week.

A significant relationship was found in weeks 5 to 8, 9 to 12 and 13 to 16 between external training load (distance) and illness incidence when the weekly training load was less than 30km per week.

b) A significant relationship was found in weeks 1 to 4, 5 to 8 and 13 to 16 between the ACWR and injury incidence when the ACWR exceeded 1.5. A significant relationship was found in weeks 13 to 16 between the ACWR and illness incidence when the ACWR was less than 0.05.

6.1 Conclusion

In conclusion, most running-related injuries found in this study were muscle related with the knee being the most common site of pain. Illness incidence was highest in the one to two week period following the Two Oceans ultramarathon event with congestion being the main illness-related symptom found. With regard to training loads, a lower training load could potentially predispose to running-related injuries or the development of illness. Specifically, a weekly mileage of less than 30km per week may increase the risk of sustaining an injury or illness when training for an ultramarathon event. Significant changes in weekly cumulative mileage (distance) may increase the risk of injury or illness in the following week. It is recommended that athletes should increase their weekly cumulative external training load by no more than five to ten percent per week. This indicates that non-gradual changes to a weekly training load, whether increases or decreases could increase the risk of incurring a running-related injury or illness. An ACWR greater than 1.5 may increase the risk of injury in the subsequent week of training and an ACWR less than 0.5 may increase the risk of illness in the following week. Maintaining an ACWR between 0.5 and 1.5, using the EWMA method of calculation, appears to be optimal in minimising the risk of sustaining a running-related injury or illness. We therefore recommend the use of both absolute and relative workloads in the monitoring of an athlete's training load with the aim of minimising injury and illness risk and maximising performance. Further research is needed to advance our understanding of training loads and injury and illness in ultramarathon runners.

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APPENDICES

APPENDIX (A): Recruitment flyer

PARTICIPANTS NEEDED FOR MASTERS RESEARCH STUDY

Does a greater training load increase the risk of injury and illness in ultramarathon runners?

REQUIRED: 2018 TWO OCEANS ULTRAMARATHON RUNNERS

THOSE INTERESTED IN PARTICIPATING SHOULD:

Be male or female runners who have qualified for the 2018 Two Oceans Ultramarathon Race

Be over the age of 20

What would participation involve?

- You will be required to log your weekly training load, injury and illness profile for 12 weeks leading up to the Two Oceans Ultramarathon Race and for four weeks following the race.

What benefit is there for you as a participant?

- Findings from the study will be emailed to you for your knowledge.
- This may enhance your knowledge in the future with regard to the development of your own training programmes and injury prevention programmes.
- Enhance you knowledge with regard to the effects of training loads, injury and illness.

If you are interested in taking part in this study and would like more information please contact: **Student Investigator:** Nicole Craddock

Email: nixcraddock07@gmail.com

APPENDIX (B): Informed Consent

University of Cape Town

Faculty of Health Sciences

Department of Health and Rehabilitation Sciences

Divisions of Communication Sciences and Disorders; Nursing and Midwifery; Occupational Therapy; Physiotherapy; Disability studies

F45 Old Main Building, Groote Schuur Hospital

MSc Exercise and Sports Physiotherapy: Does a greater training load increase the risk of injury and illness in ultramarathon runners?

Informed Consent Form

Dear Participant

I am a Masters student in the Division of Physiotherapy at the University of Cape Town. As part of the MSc Sport Physiotherapy programme, I am required to conduct a research study. Ethical approval has been granted by the Human Research Ethics Committee, Faculty of Health Sciences, University of Cape Town (HREC REF to be inserted). This study will be supervised by Dr Theresa Burgess and Professor Mike Lambert from the University of Cape Town.

I have chosen to conduct my research in the field of long distance running. I will aim to determine whether there is an association between training loads, injury and illness incidences in ultramarathon runners.

As you may know, injuries in runners, especially ultramarathon runners, are very common. In order to prevent running-related injuries and illness, healthcare providers need to understand the possible causes of these injuries and/or illnesses. Therefore, this study will aim to determine what the effect of training loads on ultramarathon runners is, and potentially determine if there is an optimal training load that may protect an athlete from injury and/or illness.

What will the study involve?

Before the study commences, you will be required to fill in a medical clearance questionnaire (to ensure safe participation in the study) and a baseline questionnaire that addresses demographics, running history, competition history, injury history and illness history.

Once this has been completed, you will be sent an online logbook every week for 12 weeks leading up to the Two Oceans Ultramarathon race and in the subsequent 4 weeks following the race. You will be required to log your weekly training distance, frequency of training sessions, duration of training session and your rate of exertion. You will also be required to log any injuries and/or illness, if any. This is so that I can monitor your training load, and determine if you sustain any injuries or illnesses during the study period- which will be a total of 16 weeks..

Confidentiality and anonymity:

To protect your privacy, any information relating specifically to your identity will be kept confidential at all times. During the study, all information will be filed and kept by the researcher (Nicole Craddock) in a locked cupboard, and for 5 years following completion.

Please note that participation in this study is entirely voluntary. Should you wish to withdraw at any time you may do so with no consequences.

Potential Risks:

There are no risks associated with taking part in this study itself. However, due to the nature of running there is a possibility that you may sustain an injury during your weekly training for the Two Oceans Ultramarathon. Should this occur, you will be referred appropriately for further assessment and management. However, this will be at your own cost.

Potential Benefits:

There are no direct benefits for taking part in this study. However, once the study has been completed, all findings will be emailed to you for your knowledge. This may help in the future with regard to the development of your own training programmes and injury prevention programmes.

What if I have any questions or concerns?:

If you have any questions or concerns about the study please do not hesitate to contact one of the individuals listed below. You are assured that all enquiries will remain confidential.

Researcher: Nicole Craddock

Contact number: 0825789824

Email: nixcraddock07@gmail.com

Supervisor: Dr. Theresa Burgess

Contact number: 021 406 6171

Email: Theresa.burgess@uct.ac.za

Chairperson, Faculty of Health Sciences, Research Ethics Committee: Professor Marc Blockman

Contact number: 021 406 6492

Email: marc.blockman@uct.ac.za

Consent statement:

I hereby confirm that I have read the informed consent form and that I understand the purpose of this study and the procedure involved. I understand that if I have any queries or concerns, I may contact the relevant persons at any time during the study. I understand that I have the right to withdraw from the study at any time should I so wish with no consequence for my withdrawal. I understand that my information will remain confidential and anonymous at all times.

By placing your signature below, it serves as confirmation that you have given your consent to partake in this study.

Signature	Name	Date
_______________	________________	________________

APPENDIX (C): Physical Activity Readiness Questionnaire (PAR-Q+)

2015 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME ____________________ DATE ____________________

SIGNATURE ____________________ WITNESS ____________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ____________________

For more information, please contact

www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

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2015 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1.	**Do you have Arthritis, Osteoporosis, or Back Problems?** If the above condition(s) is/are present, answer questions 1a-1c	If **NO** ☐ go to question 2
1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐
2.	**Do you have Cancer of any kind?** If the above condition(s) is/are present, answer questions 2a-2b	If **NO** ☐ go to question 3
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐
3.	**Do you have a Heart or Cardiovascular Condition?** *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm* If the above condition(s) is/are present, answer questions 3a-3d	If **NO** ☐ go to question 4
3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐
4.	**Do you have High Blood Pressure?** If the above condition(s) is/are present, answer questions 4a-4b	If **NO** ☐ go to question 5
4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐
5.	**Do you have any Metabolic Conditions?** *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes* If the above condition(s) is/are present, answer questions 5a-5e	If **NO** ☐ go to question 6
5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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2015 PAR-Q+

6.	**Do you have any Mental Health Problems or Learning Difficulties?** *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome* If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7	
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you **ALSO** have back problems affecting nerves or muscles?	YES ☐ NO ☐
7.	**Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure* If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8	
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐
8.	**Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia* If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9	
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐
9.	**Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event* If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10	
9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐
10.	**Do you have any other medical condition not listed above or do you have two or more medical conditions?** If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations	
10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐
	PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ______________________	

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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2015 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

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- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME ____________________ DATE ____________________

SIGNATURE ____________________ WITNESS ____________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ____________________

For more information, please contact

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Email: eparmedx@gmail.com

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APPENDIX (D): Baseline Questionnaire

Baseline Questionnaire: Demographics, Running Training history, Injury history and Illness.

*The information collected in this questionnaire will only be used for the purpose of this study. All information will remain strictly confidently at all times.

Please answer each question in the space provided or by checking the boxes as appropriate. An informed consent form must be signed prior to filling in the questionnaire.

Investigator: Nicole Craddock

Email: nixcraddock07@gmail.com

Supervisor: Dr. Theresa Burgess

Email: Theresa.burgess@uct.ac.za

Please complete the following sections:

Section A: Demographics

Section B: Training History

Section C: Competition History

Section D: Injury History

Section E: Illness History

Section A: Demographics:

Name:

Age: Date of birth:

Contact number: Email address:

Gender (Please circle): Male Female

Height (cm): Running club (if applicable):

Weight (kg): Country of residence:

Section B: Training History

Training History	
How many years have you been running for?	
How many times a week do you generally run? (over the past 6 months)	
What is your average, weekly training distance (km) over the past 6 months?	
What is your longest training distance (km) over the past 6 months?	
What is your current, average running duration (min) per training session per week?	
What is your average rate of perceived exertion, RPE, per training session per week *See Appendix E attached	
Do you partake in any alternative training modalities (i.e. cycling, resistance training, swimming etc.)? Please specify	
Have you recently increased your training load in the past 3-6 months?	

Section C: Competition History

1. Have you completed any of the following races in the last 6 months? If so, how many?

10km: Yes ☐ No ☐ How many ☐

15km: Yes ☐ No ☐ How many ☐

21.1km: Yes ☐ No ☐ How many ☐

42.2km: Yes ☐ No ☐ How many ☐

>50km: Yes ☐ No ☐ How ☐ many

2. What is your personal best time with regard to the following? (minutes)

5km:

10km:

15km:

21.1km:

42.2km:

>50km:

3. Will Two Oceans Ultramarathon 2019 be your first ultramarathon? (Please circle) Yes/No

4. If yes, how many Two Oceans have you completed? ______________________________________

5. If no, how many ultramarathons have you completed before? (Please specify)

____

Section D: Injury History (past 6 months)

Injury History		
Have you ever sustained a running-related injury before? *	Yes	No
Do you currently have a running-related injury?	Yes	No
If yes, please indicate the type of injury	Muscle	
	Tendon	
	Bone	
	Ligament	
	Joint	
	Other (please specify)	
	Do not know	
Please indicate the area of the body that is injured	Back	
	Hip	
	Quadriceps (front of thigh)	
	Hamstrings (back of thigh)	
	Groin	
	Knee	
	Calf	
	Shin	
	Ankle	
	Foot	
	Other	

*A running-related injury is defined as: Running- related pain in your legs that causes either a restriction on your running, causes you to stop running for seven days or miss three consecutive training sessions, or that requires you to consult a doctor or other health care professional

1. Have you had this injury before? (Please circle)
   Yes/No

2. How bad is your pain out of 10? (0 – no pain; 10 – excruciating pain)

   1 ____ 10

3. Has your injury stopped you from running due to the pain? (Please circle)

   Yes/No

4. If yes, how many training sessions have you missed as a result of your injury?

   ____

5. Have you received any treatment for this injury? (Please circle)

   Yes/No

6. If yes, who did you receive treatment from? (Please tick)
   - Doctor
   - Pharmacist
   - Physiotherapist
   - Biokineticist
   - Chiropractor
   - Nutritionist
   - Massage therapist
   - Other

6.1 If Other, please list:

7. Have you sustained any other running-related injuries in the past 6 months? (Please circle)

   Yes/No

8. If yes, please indicate the area of the body that was injured -

   ____

   ____

9. Did you receive any treatment for this injury? (Please circle)

   Yes/No

10. If yes, who did you receive treatment from? (Please tick)

- Doctor
- Pharmacist
- Physiotherapist
- Biokineticist
- Chiropractor
- Nutritionist
- Massage therapist
- Other

Section E: Illness History

*Illness can be defined as: a new or recurring illness that is contracted during competition or training that requires you to consult a doctor or other healthcare professional regardless of its consequence (i.e. absence from training).

Illness History					
How would you rate your health in general?					
Very good	Good	Average		Poor	Very Poor
Are you currently ill?			Yes		No
If yes, what are your main symptoms?			Sore throat		Headache
			Congestion		Stomach problems
			Fever		Fatigue
Is your illness currently preventing you from running?			Yes		No
If yes, how many training sessions have you missed due to your illness?					
Have you consulted with anyone due to your illness?			Yes		No
If yes, please specify			Doctor		Nutritionist
			Pharmacist		Other
What treatment did you receive?			Rest		Medication
			Self-remedy		Other
Have you ever previously had an illness that has prevented you from taking part in a race?			Yes		No
Have you ever previously had an illness that has resulted in time off from running?			Yes		No
If yes, how long were you off for and when was that?					

APPENDIX (E): Log book

Logbook

Name:

Week 1:

Training load:

Date	Average Distance (km)	Average duration (min)	Number of runs completed (x/week)	RPE

Run	Distance
Run 1	
Run 2	
Run 3	
Run 4	
Run 5	
Run 6	
Run 7	

Key:

Km: kilometres – total distance covered per run

Min: minutes – how much time spent running

Times/week: how many runs completed in a one week cycle

RPE: rate of perceived exertion (See Appendix E)

Weekly Injury Profile:

Date	New or recurring injury?	Pain (1-10)	Time-loss (number of training sessions missed this week)	Treatment (Yes/No)

Please indicate which area of the body you have injured:

Back	Calf
Hip	Shin
Quadricep	Ankle
Hamstring	Foot
Knee	Other

Please indicate which structure you have likely injured:

Muscle
Tendon
Ligament
Bone
Nerve
Other
Do not know

If you answered yes to treatment, who did you receive treatment from? (Please tick)

- Doctor
- Pharmacist
- Physiotherapist
- Biokineticist
- Chiropractor
- Nutritionist
- Massage therapist
- Other

Weekly Illness Profile:

Illness	New or recurring illness	Main symptoms	Time loss due to illness	Treatment (Yes/No)

1. Did you consult with anyone this week due to your illness? (Please circle)
   Yes/No

2. If yes, who did you consult with? (Please tick)
   - Doctor
   - Pharmacist
   - Physiotherapist
   - Biokineticist
   - Chiropractor
   - Nutritionist
   - Massage Therapist

3. What treatment did you receive? (Please tick)
    - Rest
    - Over the counter medication
    - Prescription medication
    - Physiotherapy
    - Chiropractor
    - Masseuse
    - Other

APPENDIX (F): Modified Rating of Perceived Exertion (RPE) scale

Modified RPE Scale

*Choose the number that best describes your level of exertion (i.e. the intensity of your activity). This is your personal opinion as to how hard you think your body is working. It should reflect how heavy and strenuous the exercise feels to you.

0	Nothing at all
0.5	Very, very weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very Strong
8	
9	
10	Very, very strong

APPENDIX (G): Visual Analogue Scale

Visual Analogue Scale (VAS)

How severe is your pain today? Please mark on the horizontal line below to indicate how bad you feel your pain is today.

No pain ____ Severe pain

Appendix (H): Ethics approval letter

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E53-46 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6626
Email: shuretta.thomas@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

04 December 2017

HREC REF: 808/2017

Dr T Burgess
Health and Rehabilitation Sciences
Division of Physiotherapy
F-floor, Old Main Building

Dear Dr Burgess

PROJECT TITLE: ASSOCIATIONS BETWEEN TRAINING LOAD AND THE RISK OF INJURY AND ILLNESS IN ULTRAMARATHON RUNNERS: A PROSPECTIVE, DESCRIPTIVE LONGITUDINAL STUDY (MSc-candidate-Ms N Craddock)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study subject to the approval from the race organisers.

Approval is granted for one year until the 30 December 2018.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

The HREC acknowledge that the student, Nicole Craddock will also be involved in this study.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.