MINIMALIST VERSUS CONVENTIONAL RUNNING SHOES: EFFECTS ON LOWER LIMB INJURY INCIDENCE, PAIN AND MUSCLE FUNCTION IN EXPERIENCED DISTANCE RUNNERS

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DECLARATION

I, Charlene Marshall, 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 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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[*] Please note: all photographs included in the dissertation were taken by the author. The models consented to all the photographs being included in this dissertation.

LIST OF ABBREVIATIONS

ATP	Adenosine Triphosphate
BMI	Body Mass Index
BPI	Brief Pain Inventory
cm	Centimetre
CV	Coefficient of Variables
DNA	Deoxyribonucleic Acid
DOMS	Delayed Onset Muscle Soreness
EIMD	Exercise Induced Muscle Damage
EMG	Electromyography
Hz	Hertz
ICC	Intraclass Correlation Coefficient
iEMG	Integrated Electromyography
ITBS	Illiotibial Band Syndrome
kg	Kilogram
$kg.m^{-2}$	Kilograms per Metre Squared
km	Kilometre
LLD	Leg Length Discrepancy
m	Metre
mm	Millimetre
$m.s^{-1}$	Metres per Second
PFPS	Patellofemoral Pain Syndrome
PNF	Proprioceptive Neuromuscular Facilitation
Q-angle	Quadriceps Angle
ROM	Range of Motion
RPE	Rate of Perceived Exertion
s	Second
SD	Standard Deviation
UCT	University of Cape Town
$°.s^{-1}$	Degrees per Second

GLOSSARY OF TERMS

Acute running related injury: Acute running related injuries are traumatic injuries such as: joint sprains; muscle strains and tears; and fractured bones[66].

Body mass index (BMI): The body mass index is defined by dividing the individual's body weight by the square of the height (kilograms per metre squared) (kg.m^{-2}) and is useful in evaluating body fat excess. The World Health Organisation defines BMI values which are below 18.5 as underweight. Values between 18.5 and 24.9 are considered normal and values over 30 are obese[7].

Conventional running shoes: These types of running shoes provide cushioning and this design was developed to decrease any impact forces which may occur at the heel or on the feet in general, as well as to avoid excessive strain on the Achilles tendon and calf muscles[16,82,138].

Endurance running: Endurance running consists of middle and long distance running events. Middle distance running events are from 800 m (metres) to 3000 m, while long distance running events include track or road races of 5000 m and longer distances[17] .

Delayed onset muscle soreness (DOMS): Delayed onset muscle soreness refers to the feelings of pain or discomfort in the muscle belly followed by exercise induced muscle damage (EIMD)[5].

Extrinsic risk factor: An external force (factors not related to the individual runner) that impacts on the body[96].

Intrinsic risk factor: An internal force (individual specific runner characteristics) that impacts on the body[96].

Leg length discrepancy (LLD): Leg length discrepancy is a condition which describes two markedly unequal paired limbs. The standard values for leg length are less than 0.5 centimetres (cm), more than 0.5-1.0 cm, more than 1.0-1.5 cm and more than 1.5 cm. If the leg length difference is found to be more than 1.5 cm, there is a LLD[54].

Minimalist running shoes: These shoes have minimal cushioning and only offer protection of the plantar surface of the foot; therefore as a result, these running shoes generate a mid-foot strike or fore-foot strike followed by lowering of the heel, mimicking a normal barefoot running gait pattern[82].

Muscle fatigue: Is the temporary reduction in muscle strength, either power or endurance and may result in the inability to continue with exercise at a mandatory power[87].

Muscle flexibility: Flexibility is the range of motion (ROM) of a joint, or series of joints, and length of muscles that cross the joints[77].

Neuromuscular adaptations: Changes in response to running that include muscle power, muscle flexibility, muscle endurance and muscle control[17].

Predisposing factor: A variable that, not always proven to be causative, is considered to be associated with the onset of an injury[66].

Q-angle (quadriceps): The Q-angle is also referred to as the quadriceps angle. It measures the patellofemoral joint mechanics. This angle is formed by the intersection of two lines. The first line is drawn from the anterior superior iliac spine to the mid-point of the patella. The second line is drawn from the mid-point of the patella to the tibial tubercle. The Q-angle is formed where these two lines intersect[60].

Running kinematics: Is the study of positions, angles, velocities, and accelerations of body segments and joints during running[36,94].

Running related injury: A running related injury may be defined as any reported muscle, joint or bone problem/injury (ie. buttock, hip, thigh, knee, shin, calf, ankle, foot) resulting from running training that required the runner to miss at least one training day or a training session[58,105].

Transition: To change (in this case, from one type of shoe into another)[110].

ABSTRACT

Background: Running is a common form of exercise and participation is increasing at a steady rate across all levels of competition. Running is associated with a high risk of injury and footwear has been proposed as one of the main extrinsic risk factors for running related injuries. Minimalist running shoes are gaining popularity, and there is anecdotal evidence to suggest that use of these shoes is increasing among runners. However, there is little or no evidence to support a potential decreased risk of lower limb injuries or improved muscle function and running biomechanics associated with running in minimalist shoes, compared to conventional shoes.

Aim: The aim of this randomised clinical trial over 12 weeks was to determine if the gradual transition (accompanied by calf muscle training), from conventional to minimalist running shoes 1) increased the risk of lower limb pain or injury and 2) improved lower limb muscle function (endurance, flexibility and power) in experienced distance runners. In addition, the effects of the transition on runner satisfaction were studied.

Specific objectives: (a) To determine whether there were significant differences in lower limb injury incidence and pain, calf endurance, lower limb muscle flexibility, lower limb muscle power, foot posture index, hallux ROM and participants' satisfaction with the type of running shoes and performance between an experimental group, that ran in minimalist shoes, and a control group that ran in conventional shoes. (b) To determine whether there were significant differences in lower limb injury incidence and pain, calf endurance, lower limb muscle flexibility, lower limb muscle power, foot posture index, hallux ROM and participants' satisfaction with the type of running shoes and performance between groups over time.

Methods: This study was a stratified randomised, single-blinded, clinical trial. Thirty-two healthy male runners between the ages of 18 and 50 years, with a minimum running experience of two years were recruited for this study. Participants were required to have run between 40 and 60 kilometres (km) per week in the six-month period prior to the study, and to be training in conventional running shoes. Participants who reported any relevant medical or surgical history, participants running in minimalist running shoes, lower limb alignment abnormalities as well as any participants who took part in any races over 21.1 km in distance during the 12 week study period were excluded from the study. Participants were assigned to either an experimental group that received minimalist running shoes, or a control group that continued training in conventional running shoes. Participants attended a familiarisation session one week before the experimental phase of the study. During familiarisation, participants gave written informed consent, completed the medical and physical activity questionnaire and the physical activity readiness questionnaire. Body composition measurements and screening tests (Q-angle and LLD) were performed. Standard testing was conducted at weeks zero (baseline testing), four, eight and twelve.

Standard testing included the assessment of lower limb injury incidence, calf endurance, hamstring and calf muscle flexibility, lower limb muscle power, foot posture index, hallux ROM and satisfaction with the type of running shoes and performance. In addition, participants were required to keep a weekly online training log for the duration of the study period. Weekly training data, session rate of perceived exertion (RPE) scores, weekly incidence of self-reported pain, the brief pain inventory, and anatomical sites of pain in the lower limbs were recorded. Participants in the experimental and control groups were also required to complete a four week training programme that commenced after baseline testing. The training programme allowed participants in the experimental group to become accustomed to running in minimalist shoes, and consisted of a progressive increase in walking and running, as well as hopping training (calf muscle training). Participants in the experimental group were required to complete all elements of the training programme, whereas participants in the control group only completed the hopping training.

Results: The main finding of this study was the low injury incidence in both the experimental and control groups. Only one participant in each group reported a running related injury during the study period. The study also found that there were significant interactions between groups over time for total number of anatomical sites of pain reported per week ($p < 0.05$). In addition, left calf endurance ($p < 0.01$), average calf endurance ($p < 0.01$), lower limb muscle power ($p < 0.05$), left hallux plantarflexion ROM ($p < 0.01$), right hallux plantarflexion ROM ($p < 0.01$), average hallux plantarflexion ROM ($p < 0.01$), left hallux dorsiflexion ROM ($p < 0.01$), right hallux dorsiflexion ROM ($p < 0.01$) and average hallux dorsiflexion ROM ($p < 0.01$) all increased over time. There were no differences between groups for these variables but there were significant differences over time. Furthermore, there were significant interactions between groups over time for general satisfaction with lower limb function ($p < 0.05$) and general satisfaction with comfort and support of shoes ($p = 0.05$). General satisfaction with lower limb function increased significantly in the experimental group at week 12, and general satisfaction with the comfort and support of shoes decreased significantly in the experimental group at week 4.

Discussion and conclusion: The results of this study support the notion that minimalist running shoes do not increase injury incidence in the lower limbs[84,110,114]. However, use of minimalist running shoes resulted in an initial increase in pain in the lower limbs during the musculoskeletal adaptation period. This increase in pain in the lower limbs may be related to the decrease in general satisfaction with comfort and support of shoes during the initial training period. In addition, minimalist running shoes do not improve lower limb muscle function in experienced distance runners over a period of 12 weeks. Clinically, this study highlights the benefits of including a transition training programme with minimalist running shoes to assist with a comfortable and successful transition to decrease the risk of sustaining a running related injury. It is recommended that future studies should evaluate the long-term effects of minimalist running shoes on lower limb injury incidence, pain and muscle function in experienced endurance runners.

CHAPTER 1: INTRODUCTION AND SCOPE OF THESIS

1.1 Introduction

Recreational and competitive distance running is a popular form of exercise. The health benefits are substantial, therefore health professionals frequently prescribe running to promote physical activity[22,49,66,118,119]. Running improves cardiorespiratory function, health and general well-being[23]. Despite these beneficial effects, runners frequently experience musculoskeletal injuries[73]. These injuries are mostly located in the lower extremities. The knee and lower leg are usually affected[22,66]. Epidemiologic evidence indicates that the annual risk of developing a running related injury varies from 37% to 56%[75,119]. The knee is the most common site of running related injuries, accounting for close to half of these injuries[66]. It is important to understand the incidence of running related injuries, risk factors associated with these injuries and methods to possibly prevent these injuries from occurring. This information can help prevent injury and long-term complications in runners and may assist runners to become independent in the management of running related injuries[66].

A running related injury develops when there is an imbalance between the injury threshold of a biological structure of the body, and the applied external load[22]. When an applied stress is too high for the musculoskeletal system to cope with, or the recovery time too short, the tissues will be weakened. These factors could lead to an overuse injury[22]. A large majority of running related injuries can be classified as overuse injuries and commonly occur in the lower extremities. According to Hreljac and Ferber[66], an overuse running related injury is an injury of the musculoskeletal system. This results from a specific structure that has been fatigued and stressed beyond its capabilities, over a period of time. It is well known that these running related injuries are associated with certain risk factors[66].

These risk factors may be classified as intrinsic or extrinsic factors[119]. Some intrinsic risk factors have been shown to have a greater effect on running related injuries compared to others[66]. These specific risk factors include high longitudinal arches (pes cavus), increased quadriceps angles (Q-angles), leg length discrepancies (LLD), ankle range of motion (ROM), degree of pronation and lower extremity alignment abnormalities[66]. Extrinsic risk factors are considered to be preventable as a runner has control over these factors. It has been estimated that over 60% of overuse running related injuries are a result of training variables[22].

The specific training variables that have most often been identified as risk factors include: training intensity; running distance; rapid increases in weekly running distance; rapid increases in weekly running intensity; and stretching habits[66]. Other general risk factors include: history of running related injuries; lack of running experience; running to compete; running surfaces; environmental conditions; psychological factors; inadequate nutrition; and footwear[66].

Much research has been focussed on the effects of footwear, as running shoes have traditionally been considered a prerequisite for running. Running shoes have various different functions such as protecting the plantar surface of the foot, providing traction between the ground and the foot, controlling motion and reducing impact forces during activity[16]. It is important to understand normal running mechanics, as different shoe types and designs may alter these mechanics and ground impact forces. During running, the foot contacts the ground shortly followed by the runner's lower limb extending and energy being generated[16]. A large proportion of energy during running is responsible for creating cushioning against the shock of the leg making contact with the ground[138]. These ground impact forces, when the foot makes contact with the ground, may contribute to injuries in the lower limbs. Heel strike of the running cycle forms an important component to understanding how different shoe designs may affect the mechanics of running as well as the ground impact forces[75,138]. Various studies have reported that footwear causes changes in lower limb stiffness, and therefore the type of running shoe may influence running mechanics and ground contact forces[16]. It is hypothesised that changes in running shoe design may be associated with possible reductions in the incidence of running related injuries[23].

1.2 Statement of the Problem

Most running related injuries happen when the foot strikes the ground[82]. It has been demonstrated that different types of running shoes result in different running gait patterns[30]. Running shoes may be divided into two main categories. The first category is conventional running shoes. These types of running shoes provide cushioning and were first developed in the 1970s[82]. This design was developed to decrease any impact forces which may occur at the heel or on the feet in general, and to avoid excessive strain on the Achilles tendon and calf muscles[16,138]. These types of shoes tend to be associated with a rear-foot strike running gait pattern. However, conventional running shoes may increase limb stiffness and alter normal running kinematics[16,82,83]. The second category is minimalist running shoes. These types of shoes are based on human evolutionary history where athletes ran in either no shoes or minimal footwear[82]. These shoes typically have minimal cushioning and only offer protection of the plantar surface of the foot. As a result, these running shoes generate a mid-foot strike or fore-foot strike followed by lowering of the heel, mimicking a normal barefoot running gait pattern. This type of running gait pattern reduces impact forces between the ground and foot[82].

This results from more ankle compliance during impact and primarily from the foot being in plantarflexion upon landing. This ultimately decreases the collision with the ground[82]. Minimalist running shoes are gaining popularity, and there is anecdotal evidence to suggest that use of these shoes is increasing among runners. However, there is little or no evidence to support a potential decreased risk of lower limb running related injuries, improved running biomechanics and improved muscle function associated with running in minimalist shoes, compared to conventional shoes. This gap in research has a significant impact on the clinical management of injuries in runners of all ages and abilities. It is not possible to provide evidence-based recommendations regarding the effects of minimalist shoes on the risk of injury and lower limb function.

1.3 Aims and Objectives

1.3.1 Aim

The aim of this randomised clinical trial over 12 weeks was to determine if the gradual transition (accompanied by calf muscle training), from conventional to minimalist running shoes 1) increased the risk of lower limb pain or injury and 2) improved lower limb muscle function (endurance, flexibility and power) in experienced distance runners. In addition, the effects of the transition on runner satisfaction were studied.

1.3.2 Specific Objectives

The specific objectives of the study were:

- To determine whether there were significant differences in lower limb injury incidence and pain, calf endurance, hamstring and calf muscle flexibility, lower limb muscle power, foot posture index, hallux ROM and participants’ satisfaction with the type of running shoes and performance between an experimental group that ran in minimalist shoes, and a control group that ran in conventional shoes.

- To determine whether there were significant differences in lower limb injury incidence and pain, calf endurance, hamstring and calf muscle flexibility, lower limb muscle power, foot posture index, hallux ROM and participants’ satisfaction with the type of running shoes and performance between groups over time.

1.4 Significance of the Dissertation

Minimalist running shoes are gaining popularity amongst recreational and competitive runners; however the short- and long-term effects on neuromuscular adaptations and running related injuries are unclear. The findings of this study will contribute to literature regarding the effects of minimalist shoes on lower limb injury incidence, pain and lower limb function. The study may be of practical relevance to runners as it may provide some insight into the process of transitioning from conventional to minimalist shoes. Clinically, the findings of this study may contribute to the evidence-based prescription of running shoes. In addition, the effects of minimalist running shoes on injury incidence are currently unknown. This study will provide some insight into injury risk associated with minimalist shoes, and may therefore contribute to safe participation in endurance running.

1.5 Plan of Development

In preparation for the randomised clinical trial of this thesis, a review of the literature on endurance running, running related injuries, predisposing factors to running related injuries, muscle adaptations in response to endurance running training and competition, instrumentation and lastly, running shoes will be presented in Chapter 2. This will be followed by a description of the study designed to examine the effects of minimalist versus conventional running shoes on lower limb injury incidence, pain and muscle function in experienced distance runners (Chapter 3). The summary and conclusion section, including recommendations for future research (Chapter 4) will complete this dissertation.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Running is a common form of exercise and is increasing in popularity at a steady rate. Running is associated with several beneficial factors and the population is becoming more health conscious however, running related injuries are occurring at an increased rate. It is unclear which main contributor is the cause of running related injuries. An important contributing factor to consider when dealing with running related injuries is running shoes as they have traditionally been considered a prerequisite for running[119].

Previous studies have established that endurance running is associated with the risk of musculoskeletal injuries[119]. The incidence of running related injuries of the lower limb at a recreational and competitive level varied from 29% to 79% at clinical and medical centres as well as reported in surveys[23,119]. The purpose of this review is to outline the components that contribute to running related injuries. Endurance running will be discussed, followed by the epidemiology, classification, location and types of running related injuries. Furthermore, predisposing factors to running related injuries will be reviewed. Muscle adaptations in response to endurance running training and competition, instrumentation and lastly running shoes will be reviewed in detail. The review will focus on current evidence for the effects of different types of running shoes on running related injuries, running kinematics and kinetics, and neuromuscular factors.

Literature was found using the following databases: Cinahl; EBSCO; Google Scholar; OVID and Science Direct. Articles and books provided by lecturers at UCT were also used. The following key words were used: '*running*', '*minimalist/barefoot running shoes',* '*running shoes*', '*shod running shoes*', '*lower limb running injuries*', '*common running injuries*', '*injury prevention*', '*running training programme', 'neuromuscular factors', 'calf raise test', 'muscle flexibility', 'muscle power', 'foot posture index', 'satisfaction questionnaire', 'hallux ROM', 'endurance running', 'injury report form',* and *'performance'.*

2.2 Endurance Running

2.2.1 Endurance Running as a Sport

Endurance running is a popular form of exercise that has shown increased participation over the past 30 years[119]. The popularity of running as a sport has increased over the years at a global level as people are becoming more health conscious. Running is inexpensive, easily accessible and applicable for all ages; therefore it has developed into a popular sport[22]. Participation varies from recreational to competitive, with varying race distances. Race distances range from 5 km to the ultramarathon distance[114]. Common distances include: 5 km, 10 km, 21.1 km, 42.2 km and 56 km races. Endurance running has therefore become a popular sport among all ages and levels of competition throughout the world and offers numerous beneficial effects[49,96].

The beneficial effects of endurance running are substantial, thus health professionals frequently prescribe running to promote physical activity[22,49,66,118,119]. Endurance running may be associated with beneficial effects for the immune system and cardiorespiratory function, improved confidence levels, and weight loss, stress relief and enhanced general well-being[23]. In addition, participation in regular endurance activity may lead to decreased levels of depression, as well as reductions in the risk of developing diabetes, cancer, cardiovascular and other diseases that are lifestyle-dependent[107]. Endurance running may also decrease inflammatory markers in persons with elevated cardiovascular risk, which may be linked to plaque destabilisation. Therefore, regular endurance activity may decrease acute coronary events[93]. Furthermore, endurance training may positively influence deoxyribonucleic acid (DNA) stability due to the adaptive effects of exercise; however, further research is required in this field[93,107]. These numerous beneficial effects contribute to the popularity of endurance running.

2.2.2 Endurance Running in South Africa and Internationally

Over the past few years, there has been an increased participation in all endurance running events both in South Africa and Internationally. In South Africa, it is estimated that approximately 1000 road races are held throughout the country annually, attracting approximately 4000 participants for some of these events[46]. South Africa hosts not one, but two major annual international running events attracting runners from all over the world. The Two Oceans is a popular running event held in Cape Town and consists of a 21 km and 56 km road race.

The Comrades is another major international running event. It is an ultramarathon road race run over a distance of 89 km, held between Pietermaritzburg and Durban. The direction of the race alternates each year between the up run starting from Durban and the down run starting from Pietermaritzburg [47].

Recent statistics showed that in 2012 the number of entrants for the Two Oceans marathon was 16315 for the 21 km half-marathon (a record field) and 9185 entrants for the 56 km ultramarathon[46]. The total number of participants entered for the Comrades marathon in 2012 was 19524 with a total of 18113 South African runners and 1168 international runners[19]. These two international running events have contributed to increasing the popularity of endurance running among recreational and competitive runners. Other popular running events which South Africa hosts include: Old Mutual Om Die Dam marathon and half-marathon; Loskop marathon and half–marathon; Spar womens' 10 km races held across the country; Knysna forest marathon and half-marathon; Foot of Africa marathon and half-marathon; Soweto marathon; and Winelands marathon and half-marathon. Other running events have not been mentioned in this literature review. Popular international endurance running events have also contributed to more people taking part. Some of these events include: Great North run in Newcastle; Big Sur marathon in California; Boston marathon; London marathon and Hood-to-coast relay in Oregon, only to mention a few. Due to the increased participation in endurance running events, more people are at risk of running related injuries[31].

Despite all of the beneficial effects of running, some detrimental effects of endurance running include: exercise induced muscle damage (EIMD); delayed onset muscle soreness (DOMS); fatigue; increased knee articular cartilage degeneration and running related injuries[18,65,66,87,119]. Runners experience frequent musculoskeletal injuries and the incidence of running related injuries is therefore high[84]. Research in the field of running related injuries dates back to the early 1970's. Various studies have investigated the aetiology of running related injuries. Many factors positively associated to injuries have been discovered. However, literature highlights the difficulty in distinguishing the exact cause of running related injuries as the aetiology of injuries may be multifactorial and diverse[49].

2.3 Running Related Injuries

2.3.1 Epidemiology

Previous studies have established that endurance running is commonly associated with the risk of musculoskeletal injuries. The incidence of running related injuries of the lower limb at a recreational and competitive level varies from 29% to 79% at clinical and medical centres as well as reported in surveys[23,119]. Taunton et al[128] investigated the effects of a 13 week training programme in preparation for the 10 km Vancouver Sun Run Race in Canada. The study demonstrated a 30% injury rate. Fredericson and Misra[49] found that the risk of sustaining an injury increased when running more than 64 km per week. Running more than 64 km per week increased the relative risk for injury to three. It was also noted that females tended to have more hip injuries than males, and males tended to have more hamstring and calf injuries than females. In addition, the annual incidence rate of running injuries may be as high as 90% in runners training for a marathon[49].

Devan et al[39] identified overuse knee injuries related to running in a prospective study. This study included 53 healthy female athletes, and a total of 10 overuse injuries were reported in nine participants. These injuries included: ITBS (n = 5); patellar tendinitis (n = 3); PFPS (n = 1); and pes anserine tendinitis (n = 1). Van Middelkoop et al[135] observed an 18% incidence of injury in 647 runners during the Rotterdam marathon, and a prevalence rate of injury of 55% during the 12 months preceding the marathon. The injury incidence was three injuries per 1000 running hours of exposure time of running[135]. A systematic review determined that the predominant site of lower limb running injuries was the knee, ranging from 7% to 50%[134]. Injuries to the foot, ankle and leg accounted for almost 40% of the remaining injuries. Epidemiological data of other common sites of injury were the lower leg (shin, Achilles tendon, calf and heel) where the incidence ranged from 9% to 32%, foot and toes where the incidence ranged from 66% to 39%, and the upper leg (hamstring, thigh and quadriceps), where the incidence ranged from 3% to 38%[134].

Davey and Tilahun[34] studied the incidence of injuries in a 10 km race in Ethiopia. This study reported an overall incidence of injury of 2% (227 of 9380 runners) that consisted of soft tissue injury (0.1%) and heat stroke (0.14%). The remaining 1.76% of injuries was not mentioned in the study. This study showed a considerably lower incidence of injury compared to other international studies mentioned in this literature review. The researchers recommended that the race should start earlier in future to possibly reduce the incidence of injury due to heat stroke. There is however, limited literature on the incidence of running injuries in other African countries. Therefore, future prospective studies in African countries are required to determine the prevalence and incidence of injury.

In South Africa, Schwellnus and Stubbs[119] investigated whether running shoe prescription affected the risk of developing a running related injury. A control group and experimental group consisting of runners were used in this study. The difference between these two groups was that the experimental group had previously undergone a clinical lower limb biomechanical assessment followed by a running shoe prescription. The control group had purchased running shoes through normal means. The study observed an overall incidence of six (experimental group) and seven (control group) injuries per 1000 running sessions. These findings indicated that there was no significant difference in injury incidence between the groups and subgroups of runners[119]. Puckree et al[103] observed the association between abnormal Q-angles and the incidence of knee injuries. However, this study only included Indian male runners. Research involving all ethnic groups is required in future research. This study determined that the incidence of knee injuries was 51% (45 of 88 runners). It was also found that 58% of the total runners had abnormal Q-angles and 67% of these runners reported knee injuries. Currently there are few researchers undertaking prospective studies to determine the prevalence and incidence of injury in runners on a national level. Future prospective research is therefore required.

2.3.1.1 Summary of the Literature: Epidemiology

In summary, approximately 80% of running related injuries occurred at or below the knee, and 20% occurred above the knee[34,39,49,66,103,119,128,134,135]. Unfortunately, very little literature on the incidence of running related injuries in African countries is available[103]. This review has therefore highlighted the lack of empirical evidence regarding the incidence of running related injuries. This indicated a need for future prospective studies in African countries to determine the prevalence and incidence of running related injuries. In addition, the aetiology of many overuse running related injuries is not yet well established. However, the fact that the majority of running related injuries occurred at or below the knee suggests that there may be some common mechanisms in the aetiology or predisposing factors[66]. In addition, the classification of running related injuries will be reviewed in the next section.

2.3.2 Classification of Running Related Injuries

Running related injuries may be classified as acute or overuse injuries. Acute running related injuries are described as traumatic injuries such as: joint sprains; muscle strains and tears; and fractured bones. Acute running related injuries occur when a single stress is applied to a structure. This stress is above the tensile limit of the structure and therefore results in a traumatic injury. However, a vast majority of running related injuries are classified as overuse[66].

Hreljac and Ferber[66] described an overuse running injury as an injury of the musculoskeletal system that develops over a period of time and occurs due to a specific structure that is fatigued and stressed beyond its capabilities. In addition, overuse running related injuries develop from repeated microtrauma due to repetitive activity[151]. This leads to local tissue damage in the form of cellular and extracellular degeneration. Furthermore an overuse injury may result from insufficient time periods between stress applications[66]. These are only two important factors that contribute to the development of overuse injuries. There are many other important factors that contribute to the development of overuse injuries and these factors will be discussed in Section 2.3.5, page 12. Moreover, there are various types of running related injuries that may occur. Common types of running related injuries will be reviewed in the next section.

2.3.3 Common Types of Running Related Injuries

Rochcongar et al[111] observed that the most common running related injuries in 1153 runners were tendonitis (66%), joint lesions of the knee and ankle (58%), and muscle injuries (47%). Taunton et al[129] investigated common injuries in a retrospective study of 2002 male and female recreational runners from 1998 to 2000. The results of this study found that patellar femoral pain syndrome (PFPS) was the most common injury reported in 331 runners. This was followed by iliotibial band syndrome (ITBS) (n = 168), plantar fasciitis (n = 158), meniscal injuries (n = 100), tibial stress syndrome (number not mentioned), Achilles tendinopathy (number not mentioned), patellar tendinopathy (n = 96), gluteus medius injuries (number not mentioned), tibial stress fractures (number not mentioned) and spinal injuries (number not mentioned). This study also recognised that participants below 34 years of age were at an increased risk of developing PFPS. Other factors such as running experience (less than eight years) and a body mass index (BMI) lower than 21 $kg.m^{-2}$ in females were significant factors that contributed to injuries such as tibial stress syndrome.

Schwellnus and Stubbs[119] investigated the effects of running shoe prescription on running injuries as described in Section 2.3.1, page 8. The study found PFPS (12.0%) to be the most frequently reported injury in the experimental group. This was followed by ITBS (7.2%), shin pain (4.8%), Achilles tendon injury (7.2%), plantar fascial injury (6.0%), and bone stress injury (3.6%). In the control group, ITBS (12.8%) was the most frequently reported injury. This was followed by shin pain (10.6%), PFPS (7.4%), Achilles tendon injury (5.3%), plantar fascial injury (2.1%) and bone stress injury (1.1%). The knee and lower leg were therefore mostly affected by running related injuries with the knee being the most common site. Injuries to the foot, ankle and leg were less common[111,119,129].

2.3.4 Anatomical Sites of Running Related Injuries

Chang et al[27] investigated the distribution of lower limb running related injuries and possible factors associated with injury. This study was descriptive and exploratory and included runners who participated in the full marathon, half marathon and 10 km 2005 ING Taipei race. Participants under the age of 18 were excluded. These runners were surveyed with a questionnaire that was used to collect data. A total of 893 completed questionnaires were analysed. The study observed that 396 (44%) of participants that completed the questionnaires reported lower limb pain that was related to running. The most common running related injury was knee pain (32.5%). This was followed by foot/ankle pain (25.3%), thigh pain (16.7%), shin pain (16.1%), lower back pain (4.8%) and hip pain (4.6%). The use of knee orthotics and ankle braces was related to a higher incidence of knee and ankle pain. It was also noted that a training duration of more than 60 minutes was associated with an increased incidence of foot pain[27].

Taunton et al[128] conducted a prospective study that involved 17 training clinics. A total of 844 runners were recruited from these respective clinics. The knee was found to be the most common site of injury, accounting for 33.7% of 249 injuries. The following sites of injury were also reported: the shin (15.2%); foot (13.2%); calf and Achilles tendon (10.0%); ankle (10.4%); hip and pelvis (9.2%); lower back (5.6%); hamstring (2.4%); and thigh (0.8%). Half of the injured runners reported that they had sustained the same injuries previously. This indicated that previous history of injury may be a predictor for sustaining running related injuries. In addition, Puckree et al[103] explored the site of running related injuries. This was a national study which took place in South Africa and included 88 runners. It was found that knee injuries accounted for 51% of injuries. Therefore, the above studies suggested that the knee was the most common site of running related injuries.

However, Rauh et al[105] observed that the shin (42.0%) was the most common site of injury in 148 injured runners from a sample of 393 runners. In female runners, this was followed by the knee (23.0%), hip (12.0%) and ankle (10.0%). However, in male runners the knee was the most common site of injury (30.0%), followed by the shin (22.0%) and ankle (13.0%)[105]. Van Middelkoop et al[135] collected data during the Rotterdam marathon. The study reported the calf (33.9%) to be the most frequently reported site of injury. This was followed by the knee (27.0%) and the thigh (17.8%). Hendricks[58] investigated factors associated with injuries in road runners. Sixteen participants sustained 50 new injuries over the 16 week study period. The study found that the most common sites of running related injuries were the calf (20.0%) and the knee (18.0%).

2.3.4.1 Summary of the Literature: Common Types and Sites of Running Related Injuries in Runners

There were differences in the most common types and anatomical sites of running related injuries but not in the pattern of these injuries[27,58,103,105,111,119,128,129,135]. This could be due to the various definitions used for a running related injury, the vast differences in the number and gender of participants, as well as race distances investigated. In summary, the most common type of running related injury was PFPS[119,129]. The most common site of running related injuries was often located in the lower extremities[27,58,103,105,128,135]. The majority of running related injuries occurred at or below the knee and the remaining injuries occurred above the knee[66]. In addition, there are numerous predisposing factors that contribute to running related injuries.

2.3.5 Predisposing Factors Contributing to Running Related Injuries

The aetiology of running related injuries is multifactorial and diverse, but may often be related to training errors[49]. Schwellnus and Stubbs[119] classified predisposing factors to running related injuries as intrinsic and extrinsic. Intrinsic (internal) risk factors affect the body internally[96,119]. Extrinsic (external) risk factors affect the body externally[96,119]. The three most common predisposing factors contributing to injury include: previous injury; a fast increase in weekly mileage; and a competitive training motive[49]. Hreljac and Ferber[66] further stated that the exact causes of running related injuries, especially overuse injuries, have yet to be determined. They did however place the majority of these risk factors into three general categories, namely: training; anatomical; and biomechanical predisposing factors. This section will highlight the possible predisposing factors that contribute to running related injuries that could be considered in the diagnosis, treatment and prevention of these injuries.

2.3.5.1 Intrinsic Risk Factors

Running related injuries may occur through intrinsic factors. These are internal factors that impact the body[96]. Intrinsic factors that will be discussed in this section include: LLD; Q-angle; muscle weakness; BMI; and hip ROM; biomechanical variables; history of previous injury; previous running experience, age and fatigue[66,71].

2.3.5.1.1 Common Factors

Some common factors such as LLD, Q-angle, muscle weakness, BMI, and ROM of the hip will be discussed to identify possible associations to running related injuries[7,22,23,39,54,60,66,75,87,96,101,118,119,128,129,135,137].

a) Leg Length Discrepancy

Leg length discrepancy is a condition that describes two markedly unequal paired limbs. Leg length discrepancy can be subdivided into two groups: a structural LLD (shortening of bony structures); and a functional LLD (results from altered mechanics of the lower limbs). In addition to this classification, persons with a LLD can be classified into two groups: LLD since childhood; and LLD which developed later in life. The standard values for leg length are less than 0.5 cm, more than 0.5-1.0 cm, more than 1.0-1.5 cm and more than 1.5 cm. If the leg length difference is found to be more than 1.5 cm, there is a LLD. It was noted that LLD was associated with musculoskeletal disorders[54]. Gurney[54] observed lower back pain, hip pain, and stress fractures were commonly associated with LLD. Common injuries such as ITBS, piriformis syndrome, hip pain and lower back pain were associated with LLD. In addition, leg length discrepancies were commonly treated with shoe/heel lifts offering pain relief.

b) Q-Angle

The Q-angle is also referred to as the quadriceps angle. It measures the patellofemoral joint mechanics. This angle is formed by the intersection of two lines. The first line is drawn from the anterior superior iliac spine to the mid-point of the patella. The second line is drawn from the mid-point of the patella to the tibial tubercle. The Q-angle is formed where these two lines intersect [60]. A Q-angle greater than 15-20° may contribute to knee extensor mechanism dysfunction and PFPS, and may lead to lateral patella mal-positioning[60,101]. Herrington and Nester[60] investigated the relationship between the Q-angle and medio-lateral positioning of the patella. This study included 109 asymptomatic runners consisting of 51 males and 58 females. Medio-lateral patella position and Q-angles were measured. This study established that the mean Q-angle in the male participants was 11.6° (standard deviation (SD) 5.2) in the left knee and 11.3° (SD 4.9) in the right knee. The mean Q-angle in the female participants was 14.4° (SD 5.2) in the left knee and 13.3° (SD 5.5) in the right knee. This study also found that 28 males and 40 females had laterally displaced patellae as well as a statistically significant increase in the Q-angle measurement. This was more evident in females as they generally had increased Q-angles compared to males. This study concluded that an increased Q-angle may have influenced the position of the patella and therefore resulted in PFPS.

In contrast, Pantano et al[101] examined the differences between peak knee valgus angles between 20 participants with high and low Q-angles during a single limb squat. There were two groups: a high Q-angle group (greater than 17°); and a low Q-angle group (less than 8°). The study determined an increased Q-angle did not significantly increase peak knee valgus during a single leg squat. This study also found that participants with a larger Q-angle had a significantly greater pelvic width to femoral ratio. It was concluded that more research is required to enhance the current knowledge regarding Q-angles however it seemed that an increased Q-angle (greater than 20°) was an important predisposing factor for possible knee injuries and running related injuries[101].

c) *Muscle Weakness*

Muscle weakness is another important intrinsic risk factor. Schreiber and Louw[118] examined a single case study. The participant ran an average of between 80 km and 100 km per week and tested positive for ITBS. This study was conducted over a period of eight weeks. The participant underwent a gluteus medius training programme. This study established that the affected hip (weak gluteus medius) had reduced in adduction at heel strike as well as at 30° knee flexion during the gait pattern. This occurred after the eight week training programme. Runners with ITBS were found to have increased adduction ROM of the hip and increased ROM of hip internal rotation. This was a result of weak hip abductor muscles on the affected side. This increased the stress on the lower limb during running and may have resulted in running related injuries[66]. This finding supported the importance of gluteus medius strength to improve proximal stability and reduce the stress on the iliotibial band to decrease knee pain. However, Sled at al[124] concluded that hip abductor strengthening did not reduce knee joint loading. Thus, there is inconclusive evidence that ITBS is related to weak hip abductor muscles leading to abnormal running mechanics.

Kellis et al[75] investigated muscle co-activation before and after the impact phase of running following fatigue. This was a cross-sectional study that involved 13 female middle-distance runners with at least five years of training experience. This study stated that once fatigue began to set in, the participants contacted the ground with an increased knee-flexion angle. This resulted from an altered balance between the agonist and antagonist muscles during the loading response. This finding may have had negative implications for joint injuries in runners. This study highlighted the importance of muscle strength of the quadriceps and hamstring muscles. Kin-Isler et al[76] noted that maximal knee extension strength was a crucial component in anaerobic performance. Runners with anterior knee pain often showed weakness of the quadriceps muscle of the involved limb, thus quadriceps strengthening was advised to reduce symptoms[55]. Hamstring strength was also an important factor in reducing and possibly preventing knee pain and running related injuries.

Devan et al[39] explored overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. This was a prospective study that included 53 healthy females. Overuse knee injuries in these participants were examined. This study concluded a decrease in hamstring strength and endurance relative to quadriceps strength and endurance were predisposing factors for overuse knee injuries. Hamstring muscle imbalances need to be corrected through conditioning and strength training to possibly prevent overuse knee injuries among female athletes. Therefore, it was important to ensure that the hip abductor, quadriceps and hamstring muscles were strong to help prevent running related injuries[39].

d) Body Mass Index

Body mass index is calculated by dividing the individual's body weight by the square of the height (kg. m^{-2})[7]. The BMI is useful in evaluating body fat excess. Aurichio et al[7] stated that the World Health Organisation defines BMI values which were below 18.5 as underweight. Values between 18.5 and 24.9 were considered normal and values over 30 were obese. Aurichio et al[7] evaluated the relationship between BMI and foot posture in 227 older females and 172 older males. Foot posture index and arch index were assessed and compared to BMI. There was a positive correlation between BMI and the arch index as well as foot posture index criteria and concluded that obese females presented with flatter feet and obese males presented with increased pronated feet. This highlighted the relationship between an increased BMI and foot posture. An increased BMI may have therefore increased the risk of sustaining a running related injury due to the relative position of the feet. Noakes[96] determined a low body mass index (less than 18.5 kg.m^{-2}) to be significantly associated with the risk of running related injuries. Therefore, it would have appeared that an increased or decreased BMI may predispose to running related injuries. However, Taunton et al[128] found that an increased BMI (greater than 26 kg.m^{-2}) was a protective factor against injury in males. This could have been due to the fact that these individuals did not train often[128]. There is therefore inconclusive evidence that a higher or low BMI is associated with running related injuries.

e) Hip Range of Motion

Normal biomechanics of the lower limb is important for optimal running. Internal rotation of the hip occurs during the swing phase and is maintained during the support phase. From mid-stance through to toe-off, the hip then externally rotates[98]. Noakes[96] highlighted the importance of normal biomechanics especially internal and external ROM of the hip. Hreljac and Ferber[66] supported this finding by stating that a lack of hip ROM contributed to overuse injuries due to undue stresses which were placed on the adjacent joints. Verrall et al[136] investigated the effect of hip joint ROM restriction on athletic chronic groin injury.

This was a prospective cohort study that included 29 male Australian football players with an average age of 21.4 years, without any previous history of groin injury. End range internal and external hip joint ROM was determined in these participants using a standard goniometer. The players were followed and assessed for chronic groin injury for two consecutive playing seasons. Four of these participants developed chronic groin injury (six weeks of groin pain and unable to participate in matches). It was found that a lower body weight (p = 0.02) and decreased total hip ROM (p = 0.03) were associated with chronic groin injury. This study concluded that hip stiffness is associated with later development of chronic groin injury and is therefore a risk factor for sustaining a running related injury. In addition, this finding is relevant to runners as runners often present with restricted hip joint ROM. However, the sample used in this study was small and therefore care must be taken when applying this conclusion to clinical practice[136].

2.3.5.1.2 Biomechanics of the Feet

Only biomechanics of the feet will be discussed in this section due to the specific scope of the research. Many biomechanical risk factors associated with overuse running related injuries were classified into two groups: kinetic control variables; and mediolateral control variables[26,45,66,94,120,137,144,146]. The kinetic variables included: the rate of impact loading; the magnitude of impact forces; the magnitude of active forces; the increased forces of the medial side of the foot; and the magnitude of knee joint forces and moments[26,94,120,144,146]. The mediolateral control variables that were commonly associated with injury were the magnitude and rate of foot pronation[66]. Ferber et al[45] investigated kinetic variables in participants with previous lower extremity stress fractures. A significant finding was that larger vertical impact forces and loading rates were observed in injured runners compared to uninjured runners. In female runners, a history of stress fractures was associated with greater vertical impact ground forces, loading rates and peak tibial acceleration.

Excessive pronation is another predisposing factor to injury. Excessive pronation may occur during the stance phase of the gait cycle[137]. Pronation is a combination of rear-foot eversion, ankle dorsiflexion and fore-foot abduction. Pronation is important during running as it acts as a protective mechanism in allowing impact forces to be diminished over an increased time period. During running, excessive pronation may increase the risk of injury due to large torques and an increase in ROM of internal tibial rotation[66]. Vincenzino et al[137] investigated the effect of two taping methods on anti-pronation in 17 female participants between the ages of 16 and 21 years. This study observed that good anti-pronation control via a taping method may be a suitable preventative strategy in runners that may have an increased risk of developing a lower limb overuse injury during running. In addition, Wyndow et al[148] stated that excessive pronation and increased rear-foot motion may produce unnecessary loads on the Achilles tendon.

Evidence suggested that an angle of more than 15° was regarded as excessive pronation and may be a predisposing factor for sustaining a running related injury[137]. Excessive pronation may therefore be related to one of the mediolateral control factors. It was evident that biomechanical variables had direct associations with running related injuries however the evidence was inconclusive. Thus, future research is required to examine and report the associations between biomechanical variables and injury[66].

2.3.5.1.3 Previous Injury History

A history of previous injuries related to running may be a risk factor for re-injury. Runners tend to continue training through pain and often do not recover fully before participation in further training, thus healing of the injured structures may be delayed [23]. When runners continued to run while injured, the already compromised structure may be unable to support the runner during training, increasing the risk of re-injury[49]. Muthuri et al[91] reviewed the history of knee injuries and knee osteoarthritis in a meta-analysis. Six electronic databases were searched and a total of 24 observational studies (20997 subjects) were included. There were seven cohort, five cross-sectional and 12 case-control studies. This meta-analysis found that the association between history of knee injuries and knee osteoarthritis was significantly different for specified injuries. These injuries included: tendon or ligament injuries; meniscus damage or meniscectomy; as well as fractures of the femur; knee or lower part of the leg, compared to unspecified injuries. It was concluded that history of knee injury is a major risk factor for the development of knee osteoarthritis. This did not depend on the study design and the definition of a knee injury. Therefore, knee running related injuries may result in re-injury and future knee pain in runners due to the development of knee osteoarthritis. In addition, Macera (1989) as cited in Buist et al[23] found that a 74% increased risk of re-injury was evident in runners with a history of previous injury. However, there appears to be a lack of current evidence regarding the association of previous injury history and current injury risk in runners, thus future research is required.

2.3.5.1.4 Previous Running Experience

A lack of running experience has been identified as a predisposing factor to overuse injuries in runners[22,129]. In addition, Bredeweg at el[22] theorised that novice runners were usually physically inactive before they start training. The musculoskeletal systems of runners that lack running experience may not be adequately developed to cope with the stresses of running, when compared to experienced runners. This places inexperienced runners at a greater risk of developing a running related injury[22]. Taunton et al[128] supported that inadequate running experience was a predisposing factor for running related injuries.

Both males and females who had a previous history of running that was below average (less than 8.5 years) were at an increased risk for sustaining tibial stress syndrome. Buist et al[23] concurred that a lack of running experience was one of the most important factors that predicted running related injuries in both male and female runners.

2.3.5.1.5 Age

Age may also be significantly associated with the risk of running related injuries. Taunton et al[129] determined that younger runners (less than 34 years) showed an increased risk of running related injuries, especially PFPS (in both females and males). However, Taunton et al[128] established that females younger than 31 years were at a decreased risk of injury. This therefore highlighted inconsistencies between the risk of injury and age in runners. This could have been due to a difference in sample size, study designs (retrospective case control and a prospective cohort design respectively), difference in male versus female ratios and a difference in study period. More recently, Van Middelkoop et al[135] identified that the number of running related injuries were not directly proportional to an increase in age. Therefore, it cannot be concluded that an increase in age is a predictor for running related injuries. Begg and Sparrow[13] studied the phases of the gait cycle in 24 healthy adults (12 young and 12 elderly). The mean age of the young participants was 28.1 years and the mean age of the elderly participants was 68.8 years. The study found that the elderly participants had reduced knee flexion and ankle plantarflexion at toe-off, reduced knee flexion during push-off and reduced ankle dorsiflexion during the swing phase compared to the young participants. It was concluded that joint angle measures at important phases of the gait cycle provided a useful indication of age-related degeneration and the control of the lower limb[13]. Therefore, due to the lack of current evidence regarding aging and current injury risk in runners, more research is required to understand potential associations.

2.3.5.1.6 Fatigue

Fatigue has been identified as a predisposing factor to running related injuries[89]. Muscle fatigue is complex and may be described as the inability to continue with exercise at a mandatory power. Fatigue is also described as a reduction in the maximum force which a muscle can exert[87,89]. Muscle fatigue may develop during low and high intensity exercise[87]. Millet and Lepers[87] stated that fatigue may originate from several potential sites located either proximal (central fatigue) or distal (peripheral fatigue) to the neuromuscular junction. In addition, central fatigue may develop during prolonged exercise. Metabolic and structural changes may also be involved in muscle fatigue. Metabolic changes included glycogen depletion and intracellular calcium accumulation. Fatigue due to short-term exercise was a result of metabolic factors or muscle damage.

Muscle damage usually occurred when eccentric contractions of the muscle were involved. However, during exercise of more than 30 minutes, the causes of muscle fatigue were multidimensional[87]. Central fatigue consists of central activation deficit as well as spinal and supraspinal factors. Millet and Lepers[87] demonstrated a decrease in integrated electromyography (iEMG) activity during a maximal voluntary contraction of the quadriceps muscles of the participants after marathon running. The decrease in maximal voluntary activation resulting from fatigue may have protected the neuromuscular system, thereby allowing recovery to commence[87].

Kellis et al[75] investigated muscle co-activation before and after the impact phase of running following isokinetic fatigue. This study was cross-sectional and took place in a neuromechanics laboratory. Female middle-distance runners with at least five years of training experience were included in the study. Electromyographic (EMG) measurements of certain muscles of the lower limbs were recorded. It was established that fatigue did not change the vastus medialis: biceps femoris EMG ratio during the preactivation phase. The EMG ratio between gastrocnemius: tibialis anterior increased during the initial landing phase after fatigue. This study concluded that the increased agonist EMG activation together with the decreased antagonist EMG activation after impact showed that the decreased muscle strength of the knee extensors and flexors altered muscle activation patterns. This occurred at the knee and ankle before and after foot impact. Therefore fatigue is an important predisposing factor that may contribute to the development of running related injuries as it alters normal muscle activation patterns[75].

Denadai et al[37] determined the effects of high intensity running to fatigue on isokinetic muscular strength in endurance athletes. Eleven well-trained male middle and long-distance runners were included. These runners had at least three years of experience and logged roughly 80 km of running training per week. The study established a reduction in isokinetic peak torque of the knee extensors after high-intensity running and was dependent on the contraction type and angular velocity. It also found a significant reduction of concentric contraction at $60°.s^{-1}$ as well as eccentric contraction of the knee extensors following high-intensity exercise. This reduction in muscle contraction may predispose to the development of running related injuries due to muscle fatigue. Fatigue was shown to increase the impact acceleration during running. This may have resulted in higher impact accelerations and forces in the shank, potentially leading to changes in running kinematics and an increased risk of overuse injuries[89].

2.3.5.2 Extrinsic Risk Factors

Extrinsic factors may also contribute to the development of running related injuries[66,96]. These are external factors that impact the body[96]. Extrinsic factors that will be discussed in this section include: training methods; training surfaces; running shoes; stretching and muscle damage[11,16,22,23,50,66,71,128,132,139,145,149].

2.3.5.2.1 Training Methods

It had been estimated that over 60% of overuse running related injuries may be associated with training variables[22]. Training variables that contributed to the development of overuse running related injuries were running distance, training intensity (speed) and volume of training (frequency and duration). These factors may be summarised as training errors. Running distance is measured in kilometres and is the distance which the runner completes on a daily basis. A high running distance increases the number of steps taken during running. Thus, the number of repetitions of the applied stress is amplified. This may place the runner at an added risk of sustaining a running related injury as the runner was shifted closer to the '*injury zone'* of the stress-frequency graph[66].

Willems et al[145] examined the plantar pressure in 58 healthy participants. Out of the 58 participants, 40 were male and 18 female. This study commenced at the start of a 20 km race. All of the participants were free of injury. Once the race was completed, 52 of the participants (who completed the run without pain) were retested. This study concluded that the plantar pressure pattern changes after a long distance run. This resulted in increased loading of the medial heel, mid-foot and metatarsals. A decreased loading of the lateral toes was also noted. In addition, this study also found that the participants had a longer foot contact time and increased contact of the metatarsals. Lastly, an elevated lateral pressure distribution during the fore-foot push-off phase was also recorded. These findings contributed to predisposing factors for running related injuries which included: stress fractures; PFPS; lower leg pain as a result of exercise; and ankle sprains. Therefore, the altered plantar pressure pattern as a result of long distance running may have added to the risk of sustaining a running related injury[145].

Runners need to follow an appropriate training programme as 60% of all running related injuries may be due to increasing running distance too rapidly[71]. An appropriate training programme involves a 10% increase in training intensity per week without excessive speed work sessions and should include adequate rest periods[71]. An increase in running distance of more than 60 km per week may contribute to running related injuries, specifically in males[71].

Training intensity refers to running speed. In a review, Hreljac and Ferber[66] recognised that increased running speeds produced greater forces on the related musculoskeletal structures. An increase in training intensity resulted in a shift to the left of the stress-frequency graph[66]. This meant that fewer repetitions were required for a structure to enter the '*injury zone'*. Therefore, the probability of injury was elevated[66]. Johnston et al[71] stated that a runner should not increase training intensity or duration by more than 10% per week. This is known as the 10% rule. Following this rule could potentially decrease the risk of sustaining running related injuries[71]. However, Buist et al[23] compared a modified training programme applying the 10% rule (13 week training programme) and a '*normal*' training programme (eight week training programme). These participants were preparing for a 6.4 km run. The *'normal'* training programme was a frequently used beginners training programme that involved running and walking intervals. However, this *'normal'* training programme did not include the 10% rule. This was a randomised control trial and the study took place over a period of 13 weeks. No significant differences between injury incidence were observed in the groups that applied the 10% rule and the *'normal'* training programme. This study highlighted the fact that many training programmes are available, but few were evidence-based[23]. Therefore, further research is required for conclusive results regarding the association between training intensity and the risk of running related injuries.

The volume of training includes frequency and duration. Frequency of training refers to the number of days a runner trains per week[128]. Yeung and Yeung[149] determined that runners who had trained for more than three days per week were at an increased risk of injury. In addition, Taunton et al[128] established that females that participated in a fixed group training programme once a week were at an increased risk of sustaining an injury. Therefore, runners should train two to three days per week to possibly decrease the risk of injury. Training duration is the time in minutes that a runner trains for, per week[23]. Yeung and Yeung[149] suggested that runners who trained for more than 30 minutes a day were at an increased risk of injury, compared to runners who trained for 15 to 30 minutes a day. Thus, 15 to 30 minutes a day of running was recommended to possibly reduce the risk of running related injuries.

Training is important to develop an individual's ability to run. This can be obtained through a training programme which consists of a balance between the different training methods. A graded training programme incorporating the correct distance, intensity and volume, for a specific runner, is needed to minimise the risk of sustaining a running related injury[132]. The biomechanical load must be low and slightly increased throughout the training programme. In addition, the training programme must load the musculoskeletal system in a sport-specific way[22,132]. A positive adaptation of structures will occur once the stress stimulus of running is optimal. In addition, adequate recovery time should form part of the training programme[22,121,132]. Despite this theoretical knowledge, current studies on the effect of interventions for preventing running related injuries in runners are scarce[22].

There is a need for well controlled trials to highlight possible interventions for the prevention of lower limb injuries in runners focusing on running training programmes[121,132].

2.3.5.2.2 Training Surfaces

Runners train on a number of different training surfaces and terrains which offer different loads and stresses during running. These training surfaces include: hard (road, asphalt and artificial track); soft (sand); gravel; and grass. The training terrain includes: flat; hilly; and sloped terrain. Overuse of a specific training surface and terrain may result in altered biomechanics therefore increasing the risk of running related injuries[71]. Uphill running is commonly reported as a predisposing factor to patellar tendinopathy[71]. Downhill running is commonly reported as a predisposing factor to ITBS[50]. Johnston et al[71] established that running on loose surfaces (such as gravel roads and trail paths) may be associated with meniscus injuries in the knee, due to an increased strain on the knee biomechanics. In addition, Telhan et al[131] examined lower limb joint kinetics during moderately sloped running. This was a crossover study and included 19 young, healthy runners. This study determined that altering the running surface slope led to changes in knee power absorption as well as hip power. It concluded that running on level and moderately inclined slopes may form a safe component of training and post-injury programmes. Therefore, a variation in training surfaces (hard, soft, grass, gravel, hilly and flat) should be considered to reduce and prevent running related injuries[50,71,131].

2.3.5.2.3 Running Shoes

Running shoes have various different functions such as protecting the plantar surface of the foot, providing traction between the ground and the foot, controlling motion and reducing impact forces during activity[16]. Running shoes may be divided into two main categories namely conventional running shoes and minimalist running shoes. The potential effects of minimalist as well as conventional running shoes will be reviewed in Section 2.6, page 35.

2.3.5.2.4 Stretching

Stretching has been defined as a movement that is applied by an external and/or internal force, which aims to increase muscle flexibility and/or joint ROM[139]. In addition, stretching is commonly used to prevent musculotendinous injuries, to enhance athletic performance, to increase flexibility of muscles and to prevent DOMS[29,29,56,147]. There are three basic types of stretching, namely: static; ballistic; and proprioceptive neuromuscular facilitation (PNF)[77].

White et al[141] examined hamstring length in participants with PFPS in a cross-sectional observational study. This study was carried out in a hospital physiotherapy department, and two groups were tested. One of the groups was diagnosed with PFPS (six males, five females). The other group was asymptomatic (13 males, 12 females). This study observed that the mean value for hamstring length for participants with PFPS was 146 ± 9°. The mean value for the asymptomatic group was 154 ± 10°. This study concluded that the group with PFPS had shorter hamstring muscles compared to the asymptomatic group. Decreased muscle flexibility may therefore increase the risk of sustaining a running related injury[141], however, further research is recommended to determine associations between stretching, flexibility and running related injuries.

Johanson et al[70] investigated the effects of a gastrocnemius stretching programme on passive ankle dorsiflexion ROM and time-to-heel-off during the stance phase of gait. This was a randomised control trial design conducted in a biomechanical laboratory setting. Nineteen participants (17 female and two male, mean age of 30.3 ± 9.8 years) that reported a history of lower limb overuse injury and that had less than 8° of passive ankle dorsiflexion ROM bilaterally, were included in the study. The control group consisted of eight participants and received no intervention. The experimental group consisted of 11 participants that took part in a static gastrocnemius stretching programme (five repetitions held for 30 seconds (s) two times daily for three weeks). The experimental group showed significantly greater passive dorsiflexion ROM on both the right and left after the stretching programme, compared to the control group. However, ankle dorsiflexion and time-to-heel-off during the stance phase of gait did not differ between the groups. Therefore, although static stretching of the gastrocnemius increased passive dorsiflexion ROM, it did not change the gait cycle[70]. Thus static stretching is not recommended to assist with changes of the gait cycle in runners[70].

Yuktasir and Kaya[150] examined the long-term effects of static and PNF stretching on ROM and jump performance. Twenty-eight healthy male participants aged between 18 and 26 years were included in this study. All of the participants had no signs of any neurological or orthopaedic disorder. The subjects were randomly assigned into three groups, a passive static stretching group (n = 10), contract-relax PNF group (n = 9) and a control group (n = 9). The first measurement was taken a day before the stretching programme as well as a post-test measurement after the stretching programme. The study did not find any significant differences between the groups in jump performance (measured with a drop jump) however, the ROM values in both the stretching groups were significantly higher than the control group. This study concluded that static and PNF stretching techniques do improve ROM. However, an increase in ROM has not yet been proven to decrease running related injuries therefore future research is required in this field.

Kasunich[72] studied the changes in lower back pain in a long distance runner after stretching the iliotibial band. A 38 year old female amateur runner with right-sided lower back and sacroiliac pain as well as a positive noble compression test and tightness of the iliotibial band on the right, was included in the study. The noble test is conducted by the investigator applying pressure on the lateral side of the injured knee directly over the femoral epicondyle. The knee is then slowly extended from a 90°knee flexion starting position. If pain is felt at 30° of knee flexion, the test is positive and indicates the possible presence of ITBS. This study found that the participant demonstrated improvement in pain once extensive stretching was included in the treatment plan. It was concluded that iliotibial band tightness may result in lower back and sacroiliac pain. A treatment programme including stretching of the iliotibial band is an important component. This study demonstrated that stretching may treat running related injuries however the possible prevention of running related injuries is not yet well understood. Although stretching is regularly prescribed for effective training and competition, there is minimal evidence regarding the specific effects of stretching[11]. Stretching prior to sporting activity has been investigated by only a few authors. It was concluded that stretching alone did not prevent injuries thereby demonstrating no benefits for injury prevention in running[140]. Therefore more research is required to determine the effect of stretching on runners as a preventative measure for running related injuries or as an appropriate treatment for injuries.

2.3.5.2.5 Summary of the Literature: Predisposing Factors Contributing to Running Related Injuries

There are numerous intrinsic and extrinsic predisposing risk factors to running related injuries. The intrinsic risk factors include: anthropometric factors; biomechanical variables; previous injury history; previous running experience; age; and fatigue[7,13,22,23,26,37,39,45,49,54,60,66,75,87,91,94,96,101,118-120,128,129,135,137,144,146]. The extrinsic risk factors include: training methods; training surfaces; running shoes; and stretching[11,16,22,23,50,66,71,128,132,139,145,149]. Acquiring knowledge and addressing intrinsic and extrinsic risk factors relating to common running related injuries is important as it could assist in the treatment of underlying problems and prevention of long-term injuries[66,151]. The influence of shoe type may be an important element in the balance between optimal loading to achieve benefits of training and overloading that leads to running related injuries. In addition, response to endurance running training and competition involves important muscle adaptations[9,10,14,15,24,61,62,65,87,104,117,142]. These muscle adaptations will be reviewed in the next section.

2.4 Muscle Adaptations in Response to Endurance Running Training and Competition

Exercise induced muscle damage and changes in muscle power and flexibility are important adaptations that occur in response to endurance running training and competition[9,10,14,15,24,61,62,65,87,104,117,142]. Exercise induced muscle damage and changes in muscle power and flexibility often occurs in endurance runners and may influence injury incidence, pain, satisfaction and muscle performance due to underlying physiological processes taking place. These adaptations will be discussed in this section.

2.4.1 Exercise Induced Muscle Damage

Exercise induced muscle damage occurs as a result of unaccustomed exercise, particularly exercise involving lengthening muscle actions, and is commonly associated with the sensation of DOMS[53,65]. During lengthening muscle actions, muscles are forcibly stretched during an active contraction, resulting in increased muscle damage compared to other types of exercise[1]. Primary damage that occurs within the muscle fibres may be divided into metabolic and mechanical damage. The mechanical damage model is more commonly accepted with regards to EIMD[130]. In the mechanical model, eccentric loading of the muscle causes lengthening of myofibrils beyond normal conditions of contraction. The normal overlapping of sarcomeres during a muscle contraction is disrupted, resulting in z-band streaming[65,130]. These structural changes may be related to the clinical symptoms of EIMD including: DOMS; swelling; increased plasma protein levels; altered passive stiffness; and a loss of muscle power[1]. These structural changes may in turn affect injury incidence, pain in the lower limbs, satisfaction and overall muscle function and performance.

Delayed onset muscle soreness refers to the feeling of pain or discomfort in the muscle belly following EIMD[5]. It typically develops within the first 24 hours after exercise, intensifies to reach a peak between 24 and 72 hours, and then slowly decreases and disappears within five to seven days[29]. Delayed onset muscle soreness is associated with stiffness, tenderness on palpation, and decreased flexibility of the affected muscle[5,29,97]. Therefore, EIMD may reduce an athlete's ability to perform after unaccustomed strenuous exercise[65]. All of these clinical symptoms of EIMD may result in a change in normal running kinematics. This may predispose runners to running related injuries, however more research is required in this field. Highton et al[61] investigated the effects of EIMD on agility and sprint performance. There were significant increases in perceived muscle soreness and significant decreases in isokinetic peak torque at 24 and 48 hours following plyometric exercise.

There were also significant increases in five and ten meters sprint time, agility time and ground contact time at the agility turning point following the exercise bout that induced muscle damage. It may be postulated that these changes may predispose runners to running related injuries, however further research is required.

Endurance running may take place aerobically or anaerobically in runners. Endurance training results in an increase in the aerobic capacity of the training musculature however, EIMD may follow to allow for this adaption to occur[9,87]. Chen et al[28] explored the effects of a 30 minute run performed daily for six days after downhill running on indicators of EIMD and running economy. Maximal voluntary isometric strength of the knee extensors, plasma creatine kinase, muscle soreness and lactate dehydrogenase activities were recorded both before and after downhill running, for a total of seven days. It was concluded that downhill running results in significant increased markers of EIMD due to the eccentric muscle contractions in the lower limb. In addition, daily running performed after downhill running did not have any adverse as well as beneficial effects on recovery of muscle damage and running economy[28]. Mancinelli et al[86] studied the effects of massage on DOMS and physical performance. A significant increase in shuttle running times for the control group was established as well as significant changes in perceived soreness, vertical jump displacement and algometer readings for the experimental group. Thus EIMD results in increased pain, decreased muscle power and decreased performance that may potentially predispose runners to running related injuries, however further research is required in this field.

2.4.2 Muscle Power

Muscle power is an important factor during running[116]. Muscle contraction is dependent on the production of adenosine triphosphate (ATP) which supplies energy and is produced by the mitochondria. During aerobic distance training and sustained exercise programmes, there is an increase in mitochondrial biogenesis and ultimately more ATP is produced. Several studies have demonstrated that endurance exercise training, such as running, improved muscle strength and performance over a period of time[9]. This improvement of muscle power was likely due to the stimulation of muscle protein anabolism. This occurred during and after aerobic exercise such as endurance running[10]. Chumanov et al[32] investigated the changes in muscle activation patterns when running step rate was increased. Forty-five, injury-free recreational runners were included. It was found that runners, who ran with an increased step rate, had an increase in muscle activity during the late swing phase, specifically gluteus maximus and medius.

This study demonstrated the possible muscle power adaptations which may occur during endurance running training and competition from an increased step rate[32]. However, this study focused on muscle power during running. The muscle power post-run was not measured therefore explaining the increased muscle power.

However, Millet and Lepers[87] reviewed articles containing alterations of neuromuscular function after prolonged running, cycling and skiing exercises. Several studies observed reductions in knee extensor muscle strength after prolonged exercise. These studies concluded that after more than two hours of running, there was an increased loss in isometric strength. This was a non-linear loss with the exercise duration. In addition, it was determined that strength loss is generally lower in concentric than isometric contractions. This loss in muscle strength was associated with muscle fatigue and muscle damage during prolonged exercise. Denadai[37] examined the effects of high intensity running to fatigue on isokinetic muscular strength in endurance athletes, as described in Section 2.3.5.1.6 (page 18). There was a reduction in isokinetic peak torque of the knee extensors after high-intensity running that appeared to be dependent on the contraction type and angular velocity. There was a significant reduction of concentric contraction of the knee extensors at $60°.s^{-1}$ as well as eccentric contraction of the knee extensors following high-intensity exercise. This reduction in muscle contraction is associated to fatigue that occurs during endurance running. This highlights the connection between EIMD, pain, fatigue and decreased muscle power[37,87].

Bentley et al[15] investigated the effect of endurance exercise on the muscle force generating capacity of the lower limbs. Fourteen healthy male volunteers participated in this study. Eleven were triathletes and three were road cyclists. All of the participants had been involved in endurance training for at least 12 months prior to the study. Lower limb recovery of muscle force generating capacity was measured at rest, as well as at six and 24 hours following a bout of cycle exercise. The analysis of lower limb recovery of muscle force generating capacity included a 6 s cycle test, a maximal isokinetic leg extension at 60, 120 and $180°.s^{-1}$, and a maximal concentric squat jump. This study found a significant reduction in isokinetic peak torque at $60°.s^{-1}$ as well as isoinertial maximum force occurred after six hours of recovery had passed. This study concluded that maximal voluntary strength is decreased for at least six hours after exhaustive dynamic exercise.

Quinn and Manley[104] examined the impact of a long training run on muscle damage and running economy in runners that were training for a marathon. Fifteen male runners that were experienced endurance runners and triathletes (more than 16 year training experience), running an average of 56.3 km, four to five times a week, were included in this study.

Serum creatine kinase concentrations, DOMS, cardiorespiratory measurements, muscle power, step rate and running economy (oxygen consumption) were assessed at 24, 48 and 72 hours following a moderately paced outdoor long training run (26 km). The study showed that serum creatine kinase levels were significantly increased at 24, 48 and 72 hours compared to baseline. There were no significant differences in running economy measurements. The study concluded that a long training run of this duration and intensity (79.3% ± 1.1% of maximum heart rate) may be well tolerated for runners training for a marathon with few adverse consequences. Unfortunately this study did not examine the effects of muscle damage on muscle power[104]. It has been predicted that muscle damage decreases muscle power and has been well documented in the research[28,61,86]. Therefore EIMD may occur during endurance running and result in fatigue, pain and decreased muscle power. This may predispose a runner to sustaining running related injuries and therefore affect injury incidence.

2.4.3 Muscle Flexibility

Endurance running may influence muscle flexibility[61]. Highton[61] examined the effects of EIMD on agility and sprint running performance in 12 healthy adults. The participants were allocated to either an experimental group, that completed 100 plyometric jumps, or to a control group. Isokinetic peak torque of the knee extensors at 60°.s^{-1} and 270°.s^{-1}, perceived muscle soreness, sprint time (5 m and 10 m), a timed agility test and ground contact time at the agility turn point were recorded at 0, 24, 48 and 168 hours post muscle-damaging exercise. Isokinetic peak torque at 60°.s^{-1} and 270°.s^{-1} was significantly decreased in the experimental group at 24 and 48 hours after plyometric exercises were performed. There were also significant increases in 5 m and 10 m sprint times, agility time and ground contact time at the agility turning point in the treatment group, indicating reductions in agility and sprint performance following EIMD[61]. Further evidence states that activities requiring rapid generation of force are impaired following muscle damaging exercise[61]. Exercise induced muscle damage may therefore affect agility and in turn potentially decrease muscle power and flexibility. The initial decrease in muscle power and flexibility due to EIMD may be a short-term effect. Muscle power and flexibility should increase over time (long-term) as the runners' musculoskeletal system begins to accept the adaptations of endurance training[9].

Moreover, an increase in passive tension was evident following a session of eccentric exercise that caused muscle damage[142]. This elevation in passive tension was present immediately after the eccentric exercise session, and was accompanied by a shift in optimum length and an elevation in active tension[142]. This change in passive and active tension may therefore affect muscle flexibility, especially of the calf and hamstring muscle groups in the lower limbs[142].

In addition, the effects of muscle-damaging exercise on physiological, metabolic and perceptual responses during endurance running and cycling was studied[24]. Ten male participants were included in this study. Measurements were taken 24 and 48 hours after EIMD and included perceived muscle soreness, creatine kinase activity, knee extensor strength and physiological (oxygen consumption), metabolic and perceptual responses during ten minute running and cycling sessions at lactate threshold. The muscle-damaging exercise significantly increased muscle soreness and creatine kinase activity. In addition, knee extensor strength significantly decreased at 24 and 48 hours and oxygen consumption increased during both cycling and running after EIMD. This increase in oxygen consumption during running could be associated with changes in lower limb kinematics and decreased ability to utilise the stretch-shortening cycle. This could be associated with a decrease in active and passive muscle flexibility as a result of EIMD however further research is required in this field.

Differences in lower limb stiffness were investigated[62]. This study included endurance and untrained athletes. The study aimed to examine whether stiffness regulation during hopping was different between eight endurance-trained athletes and eight untrained participants. Two-legged hopping was performed at 2.2 hertz (Hz). In addition, joint stiffness of the hip, knee and ankle was observed using kinetic and kinematic data. The study found that the endurance-trained athletes showed significantly increased leg stiffness. It may be postulated that endurance training may increase leg and joint stiffness. This therefore results in decreased muscle flexibility that is associated with endurance training and EIMD. Unfortunately, this study did not measure lower limb muscle active or passive flexibility thus only assumptions may be made from these results. Endurance runners may have stiffer hamstring muscles and greater pelvic obliquity[117]. This results in elevated exertion injuries around the lower back and predisposed runners to ITBS. An increased lumbar lordosis and anterior pelvic tilt are common in endurance runners. This leads to associated tightness of the hip flexors, which may be associated with the onset of lower back pain. This predisposed runners to hamstring strains[117].

Bell at al[14] investigated the effect of muscle strength and flexibility characteristics of participants with excessive medial knee displacement. The study did not specify whether the participants were endurance runners. This case control study was conducted in a sports medicine research laboratory and consisted of 37 healthy participants. Nineteen participants formed part of the control group and 18 participants tested positive for medial knee displacement (experimental group). This study demonstrated that the experimental group had greater hip external rotation strength, decreased plantarflexion strength, increased hip extension strength, and increased hip external rotation. It was concluded that the experimental group revealed tight and weak ankle musculature. This study demonstrated the connection between decreased muscle flexibility and altered kinematics. These muscle adaptations could potentially occur during endurance running training and competition if runners do not perform regular stretching sessions.

Therefore, further studies are required to investigate changes in optimal length and the length-tension relationship as well as muscle adaptations in endurance runners[142]. Therefore, EIMD and changes in muscle flexibility may influence pain, satisfaction, muscle performance and injury incidence in endurance runners.

2.4.4 Summary of the Literature: Muscle Adaptations in Response to Endurance Running Training and Competition

Exercise induced muscle damage and changes in muscle power and flexibility are important adaptations that occur in response to endurance running training and competition [9,10,14,15,24,61,62,65,87,104,117,142]. Exercise induced muscle damage occurs as a result of unaccustomed exercise, particularly exercise involving lengthening muscle actions, and is commonly associated with the sensation of DOMS[53,65]. In addition, downhill running increases markers of muscle damage[28]. Muscle power increases during exercise and over a period of time[9,32], however a decrease in muscle strength after prolonged endurance running training is evident[15,37,87,104]. Active and passive tension increases as a result of endurance running training and EIMD therefore resulting in decreased muscle flexibility[14,24,61,62,117,142]. Conversely, an increase in optimal length and active tension occurs in muscle over time[142]. These muscle adaptations that occur in response to endurance running training and competition can be measured with valid and reliable instruments.

2.5 Instrumentation

Injury incidence, calf endurance, muscle flexibility, muscle power, foot posture index, hallux ROM and satisfaction may change in response to endurance running. The various measurement instruments to measure these possible changes will be reviewed in this section. These tests include: the injury report form; the calf raise test; the ankle lunge test; the active knee extension test; the vertical jump test; foot posture index; hallux ROM and the satisfaction questionnaire[3,8,22,38,58,59,88,106,123]. These outcome measures provided accurate data which were recorded and analysed during the study.

2.5.1 Measurement of Injury Incidence

Injury incidence is an important outcome measure especially when a runner changes running shoes. This incidence value indicates the differences in injury occurrence specifically between two different groups exposed to different situations. Various previous studies have investigated incidence of the epidemiology of running related injuries as well as types and sites of running related injuries[27,39,58,105,111,119,128,129,135]. These previous studies have found the outcome measurement of incidence to be valid and reliable. An injury report form is a valid and reliable method to record any injuries sustained. The injury report form consists of columns regarding: date; week of study; type of injury; recurring injury; mechanism of injury; location of injury and training days missed. In addition, any injuries which occur during the study period between training sessions and standard testing sessions are recorded (per week) on a computerised training logbook. The injury report form and the computerised training log are both valid and reliable and have been used in previous studies therefore it was used in this study[22,58].

2.5.2 Measurement of Calf Endurance

Calf endurance is important during running as this muscle is required to contract continuously. The calf raise test is the only test available to determine changes in calf endurance and is a convenient and reliable test[56,57]. This test had a high intraclass correlation coefficient (ICC) of more than 0.80[38]. This test measured both triceps surae muscles. Initially, gastrocnemius is more active however soleus slowly takes over the activity as gastrocnemius fatigues[56,57]. This test is performed unilaterally on the edge of a step. A heel raise into full plantarflexion is performed with the knee of the tested leg in full extension. The heel raise is then followed by a slow and controlled lowering of the heel back down onto the step. This is repeated for 60 s, or until fatigue sets in. This test has been shown to be valid and reliable with standardised parameters including: body position; height of raise; pace of exertion (one full calf raise per second) and termination criteria. Termination criteria included fatigue that resulted in the inability to maintain calf raise height as well as a decrease in coordination, compensatory movements or a loss of balance[56,57]. It is vital that the knee (full extension) and ankle (plantar-grade) position, pace (one full calf raise per second) and height of each calf raise (high as possible) are standard at each testing session. This results in good intra-rater reliability. Therefore the calf raise test was chosen to measure calf endurance due to its good validity, reliability and convenience[56,57].

2.5.3 Measurement of Muscle Flexibility

Muscle flexibility is important during running as it may affect a runner's performance if imbalances are present. The ankle lunge test is valid and reliable and is used to measure soleus complex flexibility[38,123]. This test is performed by placing a tape measure along the floor against a wall. A lunge is then performed along the tape measure with the knee of the tested leg touching the wall. The distance from the tip of the first toe to the wall is recorded. This test has an ICC value of 0.99 and is therefore valid and reliable[38,123]. In addition, active and passive ROM of the ankle may be used to measure gastrocnemius and soleus complex flexibility. Passive ROM and active stiffness of the ankle joint had moderate reliability coefficients of 0.71 (30% maximal voluntary contraction), 0.78 (60% maximal voluntary contraction) and 0.68 (90% maximal voluntary contraction). Therefore, passive flexibility and active stiffness of the ankle plantarflexion muscles were autonomous measures of the components of muscle-tendon unit flexibility[68]. Therefore, this method of measuring gastrocnemius and soleus complex flexibility is not preferred. The ankle lunge test is preferred due to its good validity and reliability[123].

There are a variety of different tests that are used to assess hamstring flexibility. Some of these tests include: the passive straight leg raise test; the sit and reach test; the toe touch test; the modified sit and reach test; and the active knee extension test[8]. The active knee extension test is a valid and reliable test used to measure hamstring flexibility[8]. This test had an ICC value of 0.77 therefore demonstrating its good validity and reliability[8]. This test is performed in supine with the thigh of the tested leg positioned and secured at 90° of hip flexion. The knee is actively extended as far as possible and the extension ROM is measured with a goniometer. The hip of the tested leg must remain at 90° of flexion throughout the test. This position results in a more accurate measurement of pure hamstring flexibility. The modified sit and reach test and the passive straight leg raise test have been reported to show the greatest variability as well as the lowest absolute reliability values due to the difficult measurement procedures[8]. Therefore these two tests were not preferred to measure hamstring flexibility. Neural tension is created during the sit and reach test as well as during the toe touch test. This may influence hamstring flexibility measurement. Thus the active knee extension test was preferred to measure hamstring flexibility due to its good validity, reliability and easy measurement procedure[8].

2.5.4 Measurement of Muscle Power

Muscle power is important during running as it may affect a runner's performance if imbalances are present. The vertical jump test is a convenient, inexpensive and reliable model used to determine changes in lower limb muscle power[3]. This test is performed from a squat position with the knees flexed to approximately 90°. A jump up to reach maximum vertical height is measured in centimetres[3]. The vertical jump test had a coefficient of variation (CV) value of 3.3%. A low CV percentage indicated that the vertical jump test was a reliable and valid test of muscle power, particularly in studies that may produce small but important changes in athletic performance[63]. The single leg hop test was sometimes used to measure lower limb muscle power however, the correlation between the vertical jump test and the single leg hop test was between 0.74 and 0.71[127]. This showed that these two tests did not measure the same functional components. The standing long jump test may also be used to measure lower limb muscle power however, momentum from arm swing may influence the results therefore this test was not preferred[6]. In addition, hand-held dynamometry and isokinetic dynamometry may be used to measure muscle power. Good inter-rater reliability with ICC values of 0.90, 0.91, and 0.96 was found for these instruments[143]. Therefore a hand-held and isokinetic dynamometry is a valid and reliable tool used to measure knee flexion and extension strength however, these instruments are expensive and not readily available. Therefore the vertical jump test was the most valid, reliable and convenient test in measuring lower limb muscle power[3].

2.5.5 Measurement of Foot Posture

The posture of a runner's foot may affect the biomechanics of running and the gait cycle. It is important to determine and monitor the foot posture of a runner as excessive pronation is associated with an increase in running related injuries. Different running shoes may directly affect and change a runner's foot posture[106]. The foot posture index is used to classify the degree of pronation, supination, or whether the foot is in a neutral position. Therefore this test is used to measure the foot posture or position relative to the lower limb. It is used in this study to assess whether a change in running shoes affects foot posture. The six criteria used in the foot posture index are evaluated and include the following: talar head palpation; supra and infra malleolar curvature; calcaneal frontal plane position; prominence in the region of the talonavicular joint; congruence of the medial longitudinal arch; and adduction/abduction of the fore-foot on the rear-foot. Each criterion is scored on a scale of -2, -1, 0, +1, or +2. The results are then combined into a summative score and categorised to define the type of foot posture as follows: highly supinated (-12 to -5); supinated (-4 to -1); neutral (0 to +5); pronated (+6 to +9); and highly pronated (10+). This test is valid and reliable as it has an inter-tester reliability of 0.62 to 0.91 and intra-tester reliability of 0.81 to 0.91. In addition, the foot posture index has an ICC value of between 0.62 to 0.91[106]. Therefore this test was used as it has good validity and reliability[106].

2.5.6 Measurement of Hallux Range of Motion

Hallux ROM is important during running as excessive or limited ROM of this joint may affect performance. The hallux ROM is assessed using a hand-held goniometer. The hallux is passively dorsiflexed and plantarflexed to the end of range. The maximum angle in degrees of plantarflexion and dorsiflexion of the hallux is recorded. This test is valid and reliable when the hallux ROM is measured from a neutral joint position and the long axes of the first metatarsal and proximal phalanx are collinear in the sagittal plane[4]. In addition, this test is inexpensive[4,12,88]. Unfortunately no ICC or inter- and intra-rater reliability values were found in the literature that was searched.[88].

2.5.7 Measurement of Participants' Satisfaction with the Type of Running Shoes and Performance

A satisfaction questionnaire is a valid, convenient, inexpensive and reliable tool in measuring and assessing satisfaction. Satisfaction is an important measure as level of satisfaction is often associated and closely linked to behavioural intensions and physical performance[43,52,59,78]. A satisfaction questionnaire offers important quantitative data and has been used in many different research questions such as rugby players attitudes and behaviour towards tackling, evaluating medication-related services in a hospital setting and the measurement of body-image, only to mention a few[52,59,78]. These three studies have found that a satisfaction questionnaire offers useful, valid and reliable data when the questionnaire has undergone a developmental process by a panel of experts and a Likert scale is used[52,59,78]. This satisfaction questionnaire relating to satisfaction with the type of running shoes and performance was developed and reviewed by a panel of experts and consists of ten closed-ended questions (Appendix IV). Each question consists of the question and response categories. The response categories consist of a five point ordinal Likert Scale represented by a numerical value. The questions are related to the satisfaction of running shoes, training, injury status, performance, lower limb flexibility, lower limb muscle strength, comfort during running, the support offered from the running shoes, current feelings of continuing to run in minimalist running shoes and feelings about continuing to run in conventional running shoes. This questionnaire is therefore valid and reliable having undergone a developmental process as well as consisting of closed-ended questions and a Likert scale[59].

2.6 Running Shoes

2.6.1 History of Running Shoes

Barefoot running has been around for millions of years. Footwear was invented over 30 000 years ago. The function of this footwear was to protect the foot against acute injury. This was when shoe modifications were introduced[110]. The running shoe was only invented four decades ago. In the 1970's, the impact of running on fitness was promoted[110], and this generated interest in endurance running. The running shoe companies began to improve the fashion appearance of running shoes as well as increased cushioning and comfort. This aimed to decrease stresses associated with the repetitive impact of running[110]. The cushioned sole of running shoes became a standard feature due to the success of this design. This design continued even though there was no scientific evidence to prove a reduction in running related injuries[110]. Thereafter, the changes in running shoe technology began to focus on minimising injury and progressed to orthotic inserts into running shoes. This aimed to accommodate for different arches and foot shapes in runners. These changes included: motion control shoes for low arches; cushioned shoes for high arches; and stability shoes for normal foot arches[110]. Neutral cushion shoes aimed to provide additional shock absorption for runners with excessive supination throughout the gait cycle. Motion control shoes aimed to control any excessive pronation throughout the gait cycle[112]. These shoes included a denser midsole and a reinforced heel for runners with excessive pronation. These running shoe designs aimed to improve instability of the shoe and therefore limit excessive knee and foot motions, which may have led to running related injuries[20]. Despite these advances in running shoe technology no evidence supported a reduction in injury rates[110].

Minimalist shoes are currently the newest design and are considered as less rigid compared to conventional running shoes. It has been assumed that minimalist running shoes offer less support for the foot and lower extremity therefore stimulating and strengthening the muscles that control dynamic and static stability[20]. This should ultimately minimise injury risks however, there is currently no evidence to support this. Studies have begun to investigate the different effects of these two different types of running shoes on running related injuries, biomechanics, kinematics and neuromuscular factors. This new shift back into minimalist running shoes is stimulating great interest among runners and researchers. However, it is unclear whether minimalist running shoes decrease running related injuries and enhance muscle and running performance.

2.6.2 Barefoot Running, Minimalist and Conventional Running Shoes

This section will review the effects of barefoot running, minimalist as well as conventional running shoes on running related injuries, running kinematics, kinetics and neuromuscular factors. Training programmes to allow for transition from conventional to minimalist running shoes will also be reviewed. Experimental and review articles will be included in this section. Review articles have been included due to the limited number of experimental studies on minimalist and conventional running shoes. The current evidence regarding different types of running shoes and effects has been summarised in Table 2.1, Table 2.2, Table 2.3, Table 2.4 and Table 2.5. Table 2.1 and Table 2.2 summarises the effects of footwear on running related injuries. Table 2.3 and 2.4 summarises the effects of footwear on running kinematics and kinetics. Table 2.5 summarises the effects of footwear on neuromuscular factors. In addition, each of the articles, which have been reviewed, has been rated according to the level of evidence. These different levels of evidence have been classified according to the rating system used by Oberemskey et al[99]. This rating system ranges from level I through to level V. Level I represents a good evidence rating and level V a poor evidence rating[99].

2.6.2.1 Effects of Footwear on Running Related Injuries

De Wit et al[36] conducted a quasi-experimental study with nine trained male long distance runners. Due to the small sample size, care was taken when generalising the results. The runners in this study were injury free and ran distances of between 30 km to 40 km per week. There was only an experimental group with no control. This study[36] was rated as level II evidence[99]. The nine runners ran across a 30 m indoor force plate at three different velocities of 3.5, 4.5 and 5.5 metres per second (m.s^{-1}). The participants ran barefoot, followed by shod running. Spatiotemporal variables, ground reaction forces and sagittal and frontal plane kinematics were observed during stance phase. This study established that barefoot running had significantly larger external loading rates with a higher leg stiffness compared to running in conventional running shoes. However it was also found that barefoot running resulted in lower peak heel pressures due to the runners landing with a flatter foot. Thus, it is not clear whether barefoot running contributes to running related injuries as this study did not measure injury incidence in barefoot runners.

Braunstein et al[21] investigated whether footwear affected the adjustment at the ankle and knee joints during running. A quasi-experimental study was conducted using 14 healthy male endurance runners. One group was used with no control. The participants ran along a 20 m track in a movement analysis laboratory fitted with a floor-mounted force plate.

The participants ran at a speed of approximately 4 m.s^{-1} in six different conditions including: barefoot on grass; as well as in conventional running shoes differing slightly by midsole material; midsole geometry; spring system; cushioning; and mass of the shoes. Kinematic data were collected during these six different conditions. It was concluded that higher mechanical stress occurred in the knee joint structures during mid-stance in shod running. This study also established that conventional shoes offer an improved mechanical advantage in force generation for the ankle extensors during the push-off phase of the gait cycle compared to barefoot running[21]. This study[21] was rated as level II evidence[99]. Therefore there is no conclusive evidence as to whether conventional running shoes contribute to running related injuries. Both of these studies used small sample sizes, therefore care should be taken when analysing the results[21,36].

Schwellnus and Stubbs[119] conducted a retrospective cohort study. This study had both an experimental and control group. This study[119] was rated as level II evidence [99]. The experimental group consisted of 94 participants and the control group of 83 participants. The experimental group consisted of runners who had undergone a clinical lower limb assessment followed by a running shoe prescription prior to the commencement of the study. The control group did not receive this assessment before purchasing running shoes prior to the commencement of the study. Runners who used conventional and minimalist running shoes were included in the study. All of the participants completed a validated questionnaire that documented training history, running injury incidence and injury type in the 12 month period following the running shoe purchase. This study concluded that a clinical lower limb biomechanical assessment followed by running shoe purchase does not reduce the risk of sustaining a running related injury. The findings of this study may suggest that all runners with different biomechanical lower limb structures should be able to run in minimalist running shoes, with no change in injury risk if a proper training programme is followed[23,119].

Hreljac and Ferber[66] reviewed 74 studies that were mainly epidemiological and experimental, and focused on articles predicting the risk of injury based upon biomechanical variables. Overuse running related injuries, biomechanical and anthropometric variables were some of the outcomes measured. The review concluded that most running related injuries may be attributed to training variables and therefore these injuries should be preventable. Running shoes were included in these training variables thus, in theory, runners should not sustain running related injuries if the correct running shoes are used and a training programme is followed. This study[66] was rated as level II evidence [99]. In addition, Cheung and Ng[30] reviewed 42 articles regarding running shoes and lower limb biomechanics. The review concluded that an appropriate selection of footwear may contribute to the effective management of PFPS in runners with excessive rear-foot pronation. This review highlighted the impact conventional running shoes may have on running related injuries. However, this review did not consider minimalist running shoes[30]. This study[30] was rated as level II evidence[99].

Due to the methodological flaws of not including all types of running shoes in the above mentioned studies, careful consideration should be taken in the interpretation of the results.

Lohman et al[84] carried out a descriptive review on endurance runners and observed differences in spatiotemporal parameters, kinematics and biomechanics between shod, unshod and minimally supported running. The study established the main difference between shod and barefoot running was that the initial contact during barefoot running occurred on the fore-foot or mid-foot instead of the rear-foot. Minimalist running shoes have similar properties as barefoot running but they offer a protective surface. Conventional shoes also provide a protective role as well as offering accommodations for orthotics. However, there is no current evidence which links a decrease in injury and improved performance to specific footwear. This study[84] was rated as level III evidence[99].

Ryan et al[115] investigated the effect of three different levels of footwear stability on pain outcomes in female runners in a prospective randomised control trial. Eighty-one female runners participated and were categorised into three different foot posture types: neutral (n = 39); pronated (n = 30); and highly pronated (n = 12). The participants were then randomly assigned to one of three groups: neutral; stability; or motion control running shoes. The runners took part in a 13 week half marathon training programme. The number of training days that were missed due to pain, as well as three visual analogue scale items for pain during rest, pain during activities of daily living, and pain during running were assessed. A total of 194 training days were missed by 32% of participants. The stability running shoe group reported the fewest missed days (n = 51) followed by the control shoe (n = 79). In addition, the motion control shoe group reported increased levels of pain in all three visual analogue scale items compared to other groups. It was concluded that the current approach of prescribing in-shoe pronation control in connection with foot type is potentially injurious. Thus, motion control running shoes may be associated with an increased risk of running related injuries[115]. This study[115] was rated as level II evidence[99].

Richards et al[109] carried out a systematic review of six controlled trials and systematic reviews. Outcome measures included: running injury rates; distance; running performance; osteoarthritis risk; physical activity levels; overall health; and well-being. It was concluded that the current practise of prescribing distance running shoes involving elevated cushioned heels and pronation control systems individualised to a specific runner’s foot type is not evidence-based. This review therefore highlighted the lack of conclusive evidence that conventional running shoes reduce running related injuries. This study did not consider minimalist running shoes and barefoot running[109]. This study[109] was rated as level II evidence[99].

Rothschild[114] investigated whether there was evidence regarding the effects of barefoot and minimalist running shoes. This descriptive review concluded that biomechanical gait differences have been observed between shod and barefoot running. Barefoot running may have advantages including: improved sensory feedback; improved proprioception; and reduced impact forces. This study also highlighted the lack of evidence for injury reduction and improved performance with minimalist running shoes. This study[114] was rated as level V evidence[99]. In addition, Rixe et al[110] explored whether minimalist running shoes led to a reduction in running related injuries. This was a descriptive review that concluded a minimalist running shoe and style has been characterised by short strides and mid-foot/fore-foot strikes. There was biomechanical evidence to support the ability of minimalist runners to disperse impact forces. However, there is a lack of clinical studies to support the reduction in injury. This study[110] was rated as a level V according to the levels of evidence[99].

Table 2.1: *Effects of footwear on running related injuries: Review articles.*

Reference	Study sample	Study design	Keywords used	Databases searched	Number and type of studies reviewed	Interventions/ Outcomes reviewed	Footwear	Outcomes measured	Conclusion	Levels of evidence
Rixe et al[110]	Not specified	Descriptive review	Not specified	Not specified	Not specified	Minimalist running shoes- A reduction in running related injuries?	Minimalist running shoes	Not applicable	A minimalist running shoe/ style had been proposed to minimise running related injuries. This style was characterised by short strides and mid-foot/ fore-foot strikes. There was biomechanical evidence to support the ability of minimalist runners to disperse impact forces. However, there are no clinical studies to support a reduction in injury. Runners must transition into minimalist running shoes with caution to avoid injury.	V
Rothschild[114]	Recreational and endurance runners	Descriptive review	Not specified	Not specified	Not specified	Running barefoot and in minimalist running shoes	Barefoot and minimalist running shoes	Not applicable	Biomechanical gait differences had been seen between barefoot and shod running. Many studies had proposed that the use of barefoot running has many advantages including: improved sensory feedback; proprioception; and reduced impact forces. However, no evidence exists for a reduction in injuries and improved performance. Therefore, more research is needed in the areas of injury rates and performance.	V

Reference	**Study sample**	**Study design**	**Keywords used**	**Databases searched**	**Number and type of studies reviewed**	**Interventions/ Outcomes reviewed**	**Footwear**	**Outcomes measured**	**Conclusion**	**Levels of evidence**
Lohman et al[84]	Endurance runners	Descriptive review	Not specified	Not specified	Not specified	Shod, unshod and minimally supported running shoes	Conventional, minimalist running shoes and barefoot running	Spatiotemporal parameters, kinematics and biomechanics (double limb support, initial contact)	Initial contact during barefoot running occurs on the fore-foot or mid-foot. Minimalist running shoes have similar properties as barefoot running but provide protection for the foot. Conventional running shoes provide a protective role as well as accommodating for orthotics. Currently, there is no evidence which links running shoes to injury or that minimalist shoes decrease injury and enhance performance.	III
Richards et al[109]	Adult recreational and competitive distance runners	Review article	Distance running, performance, injury rates, osteoarthritis risk, physical activity levels, overall health and wellbeing	MEDLINE, CINAHL, EMBASE, psychInfo, Cochrane database of systematic reviews, Cochrane central register of controlled trials, SPORTSDiscus and AMED	Six controlled trials and systematic reviews	Is the prescription of distance running shoes evidence-based?	Footwear with an elevated cushioned heel and pronation control, footwear individualised to specific foot types	Running injury rates, distance, running performance, osteoarthritis risk, physical activity levels, overall health and wellbeing	The prescription of footwear with an elevated cushioned heel and pronation control for distance runners is not evidence-based.	II

Reference	**Study sample**	**Study design**	**Keywords used**	**Databases searched**	**Number and type of studies reviewed**	**Interventions/ Outcomes reviewed**	**Footwear**	**Outcomes measured**	**Conclusion**	**Levels of evidence**
Cheung and Ng[30]	Not specified	Review article	Patellofemoral, footwear, motion, kinematics, shoe, running, knee, pain	MEDLINE (PubMed), CINAHL and EMBase databases	42 articles were screened and grouped	Running shoes and lower leg biomechanics	Conventional running shoes	Kinematic data and biomechanics of the lower extremities and running shoes (kinematics transfer from the rear-foot to the patellofemoral joint)	Appropriate footwear selection may have contributed to the effective management of PFPS in runners with excessive rear-foot pronation.	II
Hreljac and Ferber[66]	Not specified	Review article	Not specified	Not specified	74 studies reviewed (epidemiological and experimental studies)	Predicting the risk of injury based upon biomechanical variables	Conventional running shoes, minimalist running shoes and barefoot running	Overuse running injuries, biomechanical and anthropometric variables	Most running injuries could be attributed to training variables; it would follow that these injuries should be preventable.	II

Table 2.2: *Effects of footwear on running related injuries: Experimental articles.*

Reference	**Subjects/ Sample and age (mean ±SD**	**Study design**	**Inclusion criteria**	**Exclusion criteria**	**Groups**	**Interventions/ Outcomes reviewed**	**Footwear**	**Outcomes measured**	**Conclusion**	**Levels of evidence**
Ryan et al[115]	81 female runners (39 neutral feet, 30 pronated feet, 12 highly pronated feet) (Age 18-50)	Prospective randomised	Ran continuously for 60 minutes, no history of running injuries, no use of foot orthotics (six months before the study)	History of surgery to the lower limbs, degenerative conditions	One group: First ran in neutral running footwear, then stability running footwear and lastly, motion control running footwear No control	Underwent a 13 week half marathon training programme	Neutral footwear (Pegasus), stability footwear (structure triax) and motion control footwear (Nucleus)	Number of training days missed due to pain and three visual analogue scale items for pain (rest, activities of daily living, running)	Findings suggested that the current approach of prescribing in-shoe pronation control was potentially injurious ($p<0.001$) for footwear conditions in both neutral and pronated foot types (motion control shoe reported increased levels of pain).	II
Braunstein et al[21]	14 male endurance runners (28.2 ± 4.5 years)	Quasi-experiment	Experienced runners running three to four sessions/ week (past five years), free of injuries (past two years)	Not specified	One group: First participants ran barefoot on grass, then ran in five different types of footwear on tartan No control	All participants ran at 4.0± 0.2 m/s along a 20 m track in a movement analysis laboratory with a floor mounted force plate	Barefoot and conventional running footwear (five different types)	Kinematic data was collected with an infrared camera system and retro-reflective markers were placed on the participants. Lower extremity kinematics and kinetics were collected	Higher mechanical stress occurred in shod running for knee joint structures during mid-stance ($p=0.03$). Improved mechanical advantage in force generation for the ankle extensors during the push-off phase during shod running ($p=0.02$, shorter ground contact times).	II

Reference	**Subjects/ Sample and age (mean ±SD**	**Study design**	**Inclusion criteria**	**Exclusion criteria**	**Groups**	**Interventions/ Outcomes reviewed**	**Footwear**	**Outcomes measured**	**Conclusion**	**Levels of evidence**
Schwellnus and Stubbs[119]	Experimental group (94) Control group (83) (20-60 years)	Retrospective cohort	Runners who underwent the sports shoe selection assessment prior to June 1999	Uncompleted questionnaires	One group: Had a clinical lower limb biomechanical assessment followed by a running shoe prescription One control	A validated questionnaire was completed which documented: training history; running injury incidence; and injury type in the 12 month period following running shoe purchase	Minimalist and conventional running footwear	Training history, running injury incidence (injuries per 1000 running sessions), and injury type	A clinical lower limb biomechanical assessment, followed by running shoe purchase, did not reduce the risk of developing a running related injury any more than following general advice.	II
De Wit et al[36]	Nine male endurance runners (23.7 ± 9 years)	Quasi-experiment	No current injuries, endurance runners (30-40km/ week)	Not specified	One group: First ran barefoot at three different velocities, then ran shod at the same three velocities No control	Barefoot and shod running was compared at three different velocities (3.5, 4.5 and 5.5 m/s) along a 30 m indoor force plate	Conventional running footwear and barefoot running	Spatiotemporal variables, ground reaction forces, sagittal plane kinematics and frontal plane kinematics during the stance phase	Barefoot running led to significantly larger external loading rates and higher leg stiffness compared to conventional shoes. Barefoot running - flatter foot placement to correlate with lower peak heel pressures ($p<0.05$).	II

2.6.2.2 Effects of Footwear on Running Kinematics and Kinetics

Schultz et al[122] explored the differences in neutral foot positions when measured barefoot compared to in shoes with varying stiffness. A sample of ten male volunteers with no foot or ankle malalignment, symptoms or injuries of the lower extremities and who did not regularly wear orthotics participated in this study. The participants ran across a track in a laboratory equipped to sample kinetic data and ran barefoot followed by Nike Frees control shoes, Nike Frees with an added fore-foot carbon plate and Nike Frees with a full length carbon plate. This study concluded that conventional running shoes tended to raise the medial longitudinal arch and dorsiflex the hallux compared to barefoot conditions. This therefore increased the overall mechanical stress in the foot. Thus, conventional running shoes may alter normal biomechanics in runners[122]. This study[122] was rated as level II evidence[99].

In contrast, Stacoff et al[126] investigated tibiocalcaneal kinematics of barefoot versus shod running. This was a quasi-experimental study and five healthy male volunteers were included. The aim of the study was to investigate the four intersegmental joints of the foot and compare calcaneal and tibial movements using skeletal markers. Intracortical bone pins with reflective marker triads were inserted into the calcaneus and the tibia. The participants then performed heel-toe running between 2.5 and 3.0 $m.s^{-1}$ along a 9.35 m runway in front of three high speed cameras along a force platform. The participants ran barefoot, then in conventional shoes, then in conventional shoes with sole modifications and finally in conventional shoes with orthotic modifications. The study concluded that calcaneal and tibial movement patterns do not differ significantly between shod and barefoot running[126]. This study[126] was rated as level II evidence[99].

Boyer and Andriacchi[20] compared conventional running shoes to an unstable shoe condition, the Masai barefoot technology. This was an experimental study which included eleven women and eight men. The control group ran in the New Balance 658 shoes while the experimental group ran in the MBT M-walk shoe. This shoe was designed to simulate unstable shoe conditions. The participants ran along an 11 m runway at a self-selected speed. Kinematic data and ground reaction force data were collected. The study concluded that the MBT M-walk shoe resulted in accommodations at the ankle. The changes in the sole of this shoe therefore offered potential therapeutic opportunities for running related conditions at the ankle without risk of injury to the hip or knee. These findings postulated that unstable shoes, such as minimalist shoes, should not pose any risks of injury to the hip and knee[20]. This study[20] had sufficient statistical power and was rated as level II evidence[99]. A recent review article[51] investigated an expanded gait assessment, evaluation and validation of minimalist footwear.

The study concluded that by using manual muscle testing and gait assessment, a professional could have determined what shoes will not harm a patient during their daily activities as well as during exercise. In addition, an increase in minimalist footwear provided substantial health benefits and improved biomechanics. This study[51] was rated as level V evidence[99].

Table 2.3: *Effects of footwear on running kinematics and kinetics: Review article.*

Reference	Study sample	Study design	Keywords used	Databases searched	Number and type of studies reviewed	Interventions/ Outcomes reviewed	Footwear	Outcomes measured	Conclusion	Levels of evidence
Gangemi[51]	Recreational and competitive long distance runners	Review article	Not specified	Not specified	Not specified	Expanded gait assessment and evaluation and validation of minimalist footwear	Minimalist footwear	Gait assessment	By using manual muscle testing, a professional can determine what shoes may not harm a patient during their daily activities as well as during exercise. In addition, an increase in minimalist footwear may provide substantial health benefits.	V

Table 2.4: *Effects of footwear on running kinematics and kinetics: Experimental articles.*

Reference	**Subjects/ Sample and age (mean ±SD**	**Study design**	**Inclusion criteria**	**Exclusion criteria**	**Groups**	**Interventions/ Outcomes reviewed**	**Footwear**	**Outcomes measured**	**Conclusion**	**Levels of evidence**
Schultz et al[122]	Ten male volunteers (30 ± 5 years)	Quasi-experiment	No on-going foot or ankle malalignment, symptoms or injuries of the lower limbs, did not regularly wear orthotics	Not specified	One group: First ran barefoot, in Nike Frees (control shoes), then in Nike Frees with an added fore-foot carbon plate and lastly, in Nike Frees with a full-length carbon plate No control	All participants ran across a track in a laboratory equipped with an eight camera optical motion capture system that sampled kinetic data	Barefoot and conventional running footwear	Multi-segment kinematic foot model and optical motion analysis system measured four intersegmental joints of the foot and the height-to-length ratio of the medial longitudinal arch	There was a high variability within subjects and shoe conditions. Footwear in general raised the medial longitudinal arch and dorsiflexed the hallux compared to barefoot conditions. This increased the mechanical stress in the foot (p=0.09).	II

Reference	Subjects/ Sample and age (mean ±SD	Study design	Inclusion criteria	Exclusion criteria	Groups	Interventions/ Outcomes reviewed	Footwear	Outcomes measured	Conclusion	Levels of evidence
Boyer and Andriacchi[20]	19 volunteers (11 women and eight men) (32.6 years)	Randomised control trial	Not specified	Not specified	One group: Ran in the MBT M-walk shoe (Masai barefoot technology) One control: Ran in the control shoe (New Balance 658)	All participants ran along an 11 m runway at a self-selected speed	Conventional running footwear and an unstable footwear condition, the Masai barefoot technology	Kinematic data was collected using an eight camera system Ground reaction force data was also collected using a force plate	Accommodations to the M-walk shoe were only found at the ankle (p=0.001, greater ankle dorsiflexion) (p=0.03, less ankle plantarflexion). These changes in the sole of this shoe may offer potential therapeutic opportunities for running related conditions at the ankle without risk of injury to the hip or knee.	II
Stacoff et al[126]	Five male volunteers (28.6 ± 4.3 years)	Quasi-experiment	Injury free with no previous injury history and clinically normal feet	Not specified	One group: First ran barefoot, then ran in the conventional shoe, then ran with sole modifications and lastly, ran with orthotic modifications No control	Intra-cortical bone pins with reflective marker triads were inserted into the calcaneus and tibia Participants performed heel-toe running between 2.5 and 3.0 m/s along a 9.35 m runway in front of three high speed cameras around a force platform	Barefoot running, conventional running footwear, three footwear sole modifications and two orthotic modifications (anterior and posterior)	Compared calcaneal and tibial movements using skeletal markers	Calcaneal and tibial movement patterns did not differ substantially between barefoot and shod running and the effects of these interventions were subject-specific.	II

2.6.2.3 Effects of Footwear on Neuromuscular Factors

Bonacci et al[17] reviewed the neuromuscular adaptations to training, injury and passive interventions. These neuromuscular adaptations included muscle power, muscle flexibility, muscle endurance and muscle control. During running, energy was transferred between the athlete and the surface. An interaction formed between the running shoes and surface. Performance may be influenced by footwear and may therefore alter running patterns, muscle activity and neuromuscular factors. It has been observed that orthotics exhibited short-term effects on muscle activity during running however, these changes showed high inter-individual variability. Individual runners may demonstrate different neuromuscular changes when orthotics are used. Footwear mass may affect energy requirements. Research observed that heavier footwear increased oxygen consumption during running[17]. Oxygen consumption and EMG activity has also been studied. Research has shown that running economy responses to different shoe mass are highly individual. The EMG activity was also individual-specific. It was concluded that EMG preactivation may control leg stiffness and improve elastic energy return. However, care should be taken when interpreting the findings of this review article[17].

In this review, no studies were found which measured running economy and EMG activity of the leg muscles at the same time. Three studies were found which investigated the effect of orthotics on running economy. Two of these studies found that running economy did not change with orthotics. The third study stated that both semi-rigid and flexible orthotics led to significant increased oxygen consumption. These findings occurred in runners who had a history of running related injuries. This review concluded that footwear and the possible use of orthotics elicits individual-specific short-term effects on neuromuscular factors and control during running. However, there was no conclusive evidence to support whether footwear and orthotics decreased energy expenditure, minimised muscle activity and improved overall running performance[17]. This review article[17] was rated as level I evidence[99].

Table 2.5: *Effects of footwear on neuromuscular factors: Review article.*

Reference	Study sample	Study design	Keywords used	Databases searched	Number and type of studies reviewed	Interventions/ Outcomes reviewed	Footwear	Outcomes measured	Conclusion	Levels of evidence
Bonacci et al[17]	Endurance sportsmen including running, cycling and triathlon	Review article	Running economy, oxygen consumption, EMG, muscle activity, neuromuscular, orthoses, orthotics, shoes, resistance training, plyometrics, injury, cycling, triathlon	Cinahl, MEDLINE, PubMed, SportDiscus and Web of Science	Not specified	Neuromuscular adaptations to training, injury and passive interventions	Conventional footwear	Neuromuscular adaptations including: muscle power; muscle flexibility; muscle endurance; and muscle control	Performance was influenced by footwear and may therefore alter running patterns, muscle activity and neuromuscular factors. Each individual runner will demonstrate different neuromuscular changes when orthotics are used. Footwear mass may also effect energy requirements. Heavier footwear increased oxygen consumption during running. However, there is no conclusive evidence to support whether footwear and orthotics decrease energy expenditure, minimise muscle activity and improve overall running performance.	I

2.6.2.4 Training Programmes to Allow for Transition from Conventional to Minimalist Running Shoes

Rixe[110] reviewed whether minimalist running shoes reduced running related injuries. It was important that runners transitioned into minimalist running shoes with caution to avoid acute injury. This highlighted the importance of a specific training programme for the transition period. The transition must be gradual and take place over a period of between four to eight weeks. A runner must incorporate a training programme that includes the following: plantar sensitivity adaptation; foot strike pattern and changes in stride length and rate; lower limb proprioceptive training; ankle joint flexibility; intrinsic foot power; and eccentric strength of the lower extremity. A runner must also adapt to a reduced heel strike style during this transition period[110]. Runners must practise walking barefoot indoors and outdoors. Running form drills, proprioceptive exercises (single-leg exercises), flexibility exercises (calf stretches), intrinsic foot muscle strengthening and plyometric activities (hops, dynamic squats and jumps) should all form part of the transition programme[114]. A runner should also start the transition programme with walking, then gradually introduce running. The training surface should start with a grassy field or rubberised track and progress to smooth paved surfaces after nine weeks. This is a good transition training programme to follow as it incorporates and focuses on the different components required in order to convert and run safely in minimalist shoes. However, there is minimal evidence with regards to transitioning programmes therefore it is clear that more outcome-based research is needed[114].

2.6.2.5 Summary of the Literature: Running Shoes

Various experimental studies and review articles have been conducted[17,20,21,30,36,51,66,84,109,110,114,115,119,122,126]. However, very few studies comparing conventional and minimalist running shoes were found in the databases that were searched. Six experimental studies were found comparing conventional shoes, minimalist shoes and barefoot running[21,36,115,119,122,126] and one experimental study comparing conventional shoes and an unstable shoe condition[20]. In summary, there is no conclusive evidence with regards to footwear and the effect it has on running related injuries, running kinematics, kinetics and neuromuscular functions. However, it is clear that transitioning into minimalist running should take place slowly[110,114]. Thus, at present, there is a lack of research on all running footwear, especially minimalist running shoes[114].

2.7 Summary

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Endurance running is a popular form of exercise with increased participation over the past 30 years[119]. There is a high incidence of running related injuries[84]. Various studies have investigated the possible causes of running related injuries. Many factors have been positively associated to running related injuries. However, literature highlights the difficulty in distinguishing the exact cause of running related injuries as the aetiology is multifactorial and diverse[49].

There are differences in the most common types and anatomical sites of running related injuries but not in the pattern of these injuries. The majority are often located in the lower extremities at or below the knee, and the remaining injuries occur above the knee[66]. These running related injuries are often associated with predisposing risk factors. Acquiring knowledge and addressing intrinsic and extrinsic predisposing risk factors relating to common running related injuries is important, as it could assist in the treatment of underlying problems and prevention of long-term injuries during endurance running. Endurance running training and competition results in important changes that include muscle damage, muscle power and muscle flexibility. These changes may result in a positive or negative long-term effect on runners. Due to the current literature on this topic, it can be concluded that running footwear, fatigue and muscle damage may affect muscle strength, endurance, flexibility, running kinematics and performance of an endurance runner [9,10,14,15,24,61,62,65,87,104,117,142].

Running shoes are an important extrinsic risk factor for running related injuries. Anecdotally, minimalist running shoes are gaining popularity due to the proposed reduction in injuries and the improvement in performance[51,66,84,110,114]. There is currently equivocal evidence regarding different types of running shoes and associated effects on running related injuries, running kinematics, kinetics and neuromuscular functions [114]. Accordingly, the aim of this randomised clinical trial over 12 weeks was to determine if the gradual transition (accompanied by calf muscle training), from conventional to minimalist running shoes 1) increased the risk of lower limb pain or injury and 2) improved lower limb muscle function (endurance, flexibility and power) in experienced distance runners. In addition, the effects of the transition on runner satisfaction were studied.

CHAPTER 3: MINIMALIST VERSUS CONVENTIONAL RUNNING SHOES: EFFECTS ON LOWER LIMB INJURY INCIDENCE, PAIN AND MUSCLE FUNCTION IN EXPERIENCED DISTANCE RUNNERS

3.1 Introduction

Endurance running is commonly associated with the risk of musculoskeletal injuries. The annual incidence of running related injuries of the lower limb at recreational and competitive levels varies from 29% to 79% respectively[23,119]. The predisposing factors and aetiology of running related injuries are multifactorial and diverse, but are often related to training errors[49]. Much research has been focussed on the effects of footwear, as running shoes have traditionally been considered a prerequisite for running as well as an important predisposing factor for running related injuries. Running shoes have various different functions such as protecting the plantar surface of the foot, providing traction between the ground and the foot, controlling motion and reducing impact forces during activity[16]. Major advances have been made in running shoe technology over time, which aim to simulate barefoot running[82,138]. Minimalist running shoes are based on human evolutionary history where athletes ran in either no shoes or minimal footwear[82]. These shoes have minimal cushioning and only offer protection of the plantar surface of the foot, therefore differing from conventional running shoes.

Minimalist running shoes are gaining popularity, and there is anecdotal evidence to suggest that use of these shoes is increasing among runners. However, there is little or no evidence to support a potential decreased risk of running related lower limb injuries or pain, as well as an improvement in muscle function (endurance, flexibility and power) associated with transitioning from conventional running shoes to minimalist shoes[114]. Accordingly, the aim of this randomised clinical trial over 12 weeks was to determine if the gradual transition (accompanied by calf muscle training), from conventional to minimalist running shoes 1) increased the risk of lower limb pain or injury and 2) improved lower limb muscle function (endurance, flexibility and power) in experienced distance runners. In addition, the effects of the transition on runner satisfaction were studied. The study objectives have been described in Section 1.3 (page 3).

3.2 Methodology

3.2.1 Participants and Study Design

This study was a stratified randomised, single-blinded, clinical trial. The participants included 31 male endurance runners.

3.2.1.1 Inclusion Criteria

Healthy males between 18 and 50 years of age, who ran in conventional running shoes, were recruited for the study. The participants were required to run between 40 km and 60 km per week in the six-month period prior to the study. In addition, the runners needed to have a minimum running experience of two years. Females were excluded from this study due to hormonal changes that are associated with the menstrual cycle, which may influence running performance[100].

3.2.1.2 Exclusion Criteria

Participants who reported any relevant medical or surgical history, including a history of lower limb or lumbar spine injury or pathology within the last three months prior to the study, were excluded. Participants that were already running in minimalist running shoes were also excluded from the study. Other exclusion criteria included increased Q-angles (more than 14°) and a LLD (discrepancy of more than 15 millimetres) (mm). These intrinsic factors may increase the risk of injury[66]. Participants who took part in any races over 21.1 km during the study period were also excluded from the study, as competitive running over longer distances may be associated with an increased risk of running related injuries. In addition, competitive running over longer distances may result in EIMD and DOMS, which could influence participants' performance of testing procedures[1,65]. If a participant sustained an injury during the 12 week study period, they were not required to perform further testing. A running related injury may be defined as any reported muscle, joint or bone problem/injury (ie. buttock, hip, thigh, knee, shin, calf, ankle, foot) resulting from running training that required the runner to miss at least one training day or a training session[58,105]. The data from these participants were still included for analysis as injury incidence was one of the primary outcome measures in this study.

3.2.2 Sample Size Determination

The incidence of running related injuries varies from 2% to 90%[34,49]. The variability in injury incidence appears to be related to the extent of endurance training and competition, and the time period during which incidence is being assessed[49,119]. The main factors that were considered when performing the power calculation for this study were that participants were trained endurance runners who were required to complete an average of 40 km to 60 km of running training per week; and that the study period was over 12 weeks. A two-proportions (Z-test) power calculation was performed in Statistica (StatSoft, Inc. 2004. STATISTICA, Data Analysis Software System, Version 11, www.statsoft.com). With statistical significance accepted as $p < 0.05$, an anticipated injury incidence of 50% in the experimental group, and an anticipated injury incidence of 5% in the control group, groups of 15 participants would provide 82% power. In addition, with an anticipated injury incidence of 60% in the experimental group, and an anticipated injury incidence of 5% in the control group, groups of 15 participants would provide 94% power.

3.2.3 Sampling Method - Stratified Allocation

Participants were allocated to an experimental group that trained in minimalist shoes, and a control group that trained in conventional shoes. Participants were matched in both groups through a process of stratified allocation. Training history and age were used to match the two groups. Each participant was then ranked according to the total years of running experience and age. Years of running experience was the primary allocation criterion and age was the secondary allocation criterion. The ranking ranged from maximum to minimum. A coin was then flipped to determine which group received the first participant. '*Heads*' indicated that the experimental group received the first participant. '*Tails*' indicated that the control group received the first participant. The first participant on the list was then allocated to that specific group. Thereafter, the remaining participants were alternately allocated to each group. An independent auditor was present to conduct and observe the procedure. This process of stratified allocation occurred after the familiarisation session was conducted and the screening tests, informed consent, questionnaires, and anthropometric tests had been completed.

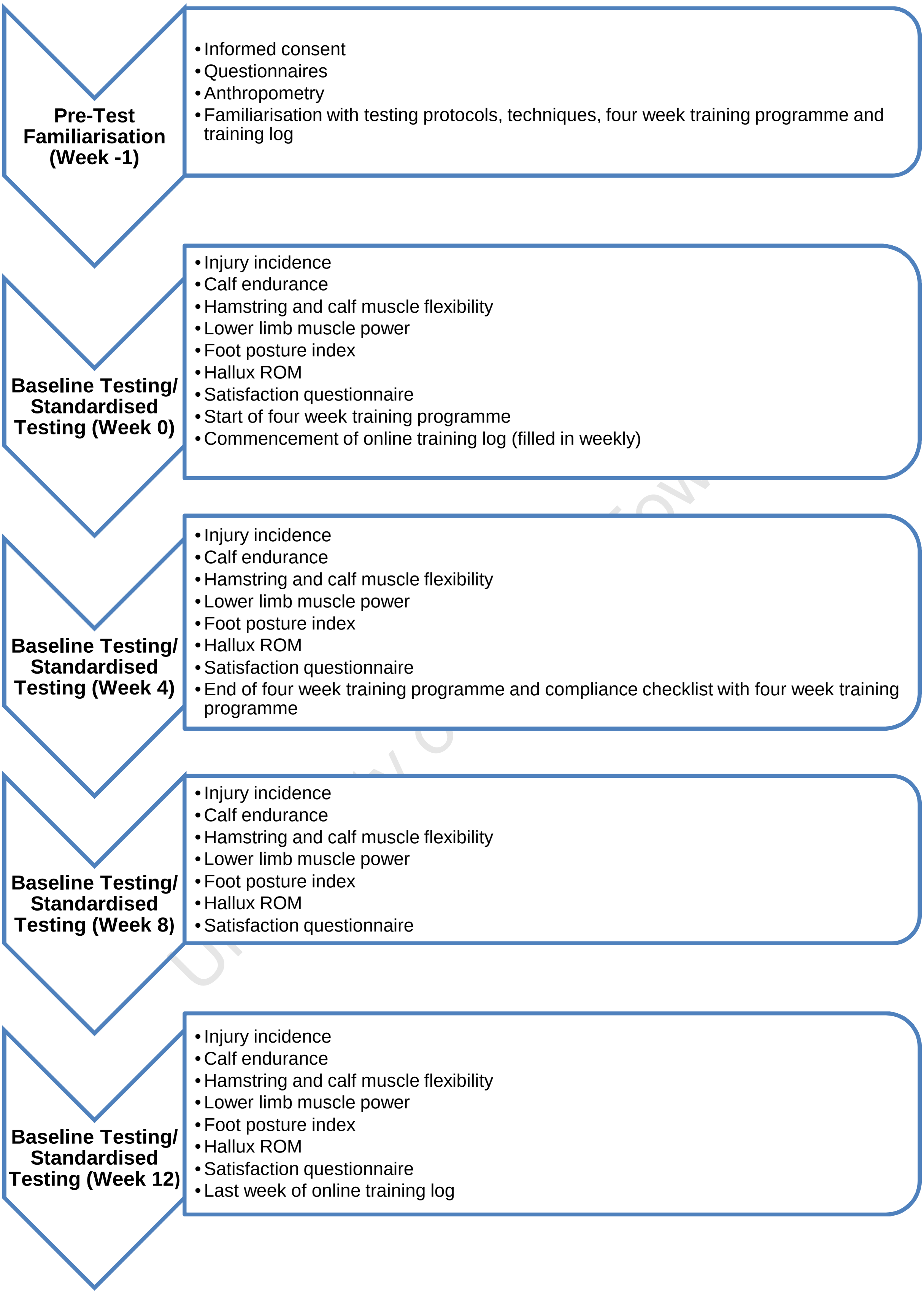
3.3 Study Procedure

Ethical approval was granted by the Faculty of Health Sciences Human Research Ethics Committee of UCT (Appendix XIII). Participants were then recruited for the study. Participants were recruited through word-of-mouth and advertisements on Facebook, at running clubs and at the Nelson Mandela Metropolitan University in Port Elizabeth. The advertisement included information regarding the study such as eligibility, location, procedure, and that participation was purely on a voluntary basis with no financial compensation (Appendix XVI). Eligible participants were required to complete an informed consent form (Appendix I). The testing phase ran over a period of approximately 12 consecutive weeks.

Participants attended a familiarisation session one week before baseline testing. The familiarisation session included a full explanation of the procedure, process and nature of the study and completion of the informed consent form (Appendix I), the Medical and Physical Activity Questionnaire which was adapted from Thomas, 1992[133] (Appendix II) and the Physical Activity Readiness Questionnaire[67,133] (Appendix III). This questionnaire was administered to ensure that participants could participate safely in physical activity. Participants were also screened for a LLD and Q-angles. Body composition measures (body mass, stature, BMI, sum of seven skinfolds, predicted percentage of body fat and lean body mass) were recorded. Baseline testing procedures were explained and participants had an opportunity to practise the physical tests. Participants were also familiarised with the training log, the four week training programme, the injury report form and the satisfaction questionnaire.

After randomisation, baseline testing was performed (week zero). At the beginning of each testing session (week zero, four, eight and 12), a warm-up was conducted to minimise the possible onset of painful and stiff muscles due to some of the testing procedures. This warm-up consisted of a ten minute jog on a treadmill at speed nine. Injury incidence was recorded using an injury report form. Calf endurance was measured using the calf raise test. Flexibility of the hamstring and soleus complex muscles was measured using the active knee extension test and the ankle lunge test respectively. Lower limb muscle power was assessed using a vertical jump test. Standing foot posture was measured using the foot posture index. Hallux plantarflexion and dorsiflexion ROM were measured using a hand-held goniometer. Lastly, participants' satisfaction with the type of running shoes and performance was recorded using a satisfaction questionnaire. These standard tests were repeated at four, eight, and 12 weeks post-baseline testing. A compliance checklist was completed at the four week data collection session. This checklist determined compliance with the four week training programme (Appendix XI).

After baseline testing, participants in both groups performed calf muscle training (hopping) for four weeks. Participants in the experimental group also underwent a gradually progressive running four week training programme that was designed to facilitate adaptation to running in minimalist shoes (Appendix X). The control group continued with their usual individual running training. In both groups, participants continued with their usual individual running training after the four week training programme. Participants were also required to record weekly training distance and time, weekly incidence of self-reported pain, brief pain inventory (BPI) scores, anatomical sites of pain in the lower limbs, and sessional RPE scores in an electronic online training log for the duration of the study (Appendix V). The minimalist running shoes were sponsored by INOV8. Participants in the experimental group collected the shoes from PC Agencies in Port Elizabeth before the study commenced. The allocation and collection of minimalist shoes was supervised by the research assistant. The study design is summarised in Figure 3.1.



Pre-Test Familiarisation (Week -1)

- Informed consent
- Questionnaires
- Anthropometry
- Familiarisation with testing protocols, techniques, four week training programme and training log

Baseline Testing/ Standardised Testing (Week 0)

- Injury incidence
- Calf endurance
- Hamstring and calf muscle flexibility
- Lower limb muscle power
- Foot posture index
- Hallux ROM
- Satisfaction questionnaire
- Start of four week training programme
- Commencement of online training log (filled in weekly)

Baseline Testing/ Standardised Testing (Week 4)

- Injury incidence
- Calf endurance
- Hamstring and calf muscle flexibility
- Lower limb muscle power
- Foot posture index
- Hallux ROM
- Satisfaction questionnaire
- End of four week training programme and compliance checklist with four week training programme

Baseline Testing/ Standardised Testing (Week 8)

- Injury incidence
- Calf endurance
- Hamstring and calf muscle flexibility
- Lower limb muscle power
- Foot posture index
- Hallux ROM
- Satisfaction questionnaire

Baseline Testing/ Standardised Testing (Week 12)

- Injury incidence
- Calf endurance
- Hamstring and calf muscle flexibility
- Lower limb muscle power
- Foot posture index
- Hallux ROM
- Satisfaction questionnaire
- Last week of online training log

Figure 3.1: *Study design.*

3.3.1 Familiarisation Session

3.3.1.1 Informed Consent

All participants were required to complete an informed consent form prior to commencement of testing at the familiarisation session (Appendix I). The possible risks and benefits associated with the study, how confidentiality would be maintained, and the participants' right to withdraw at any stage were discussed.

3.3.1.2 Questionnaires

The Medical and Physical Activity Questionnaire[67,133] was completed to determine physical activity levels, running history, injury history, and any exclusion criteria for participation in this study (Appendix II). The sections related to injury history, medical history and running history were adapted for the purposes of this study. These adaptations were made to make the questionnaire relevant and applicable to experienced endurance runners. The reliability and validity of the revised Medical and Physical Activity Questionnaire was assessed in a reliability study (Section 3.3.5, page 70). Participants were also required to complete the Physical Activity Readiness Questionnaire[67,133]. This questionnaire was administered to screen participants for safe participation in physical activity (Appendix III).

3.3.1.3 Screening Tests

Screening tests were performed to determine the presence of a significant LLD or an increased Q-angle. Previous studies have identified that these factors may increase the risk for running related injuries[54,101]. Herrington and Nester[60] investigated the relationship between the Q-angle and medio-lateral positioning of the patella and found that females generally had increased Q-angles compared to males. Therefore males were used in this study. In addition, it has been noted that a LLD was associated with musculoskeletal disorders[54]. Therefore participants that presented with one or both of these intrinsic risk factors for running related injuries were excluded from the study.

a) Leg Length Discrepancy

Leg length was measured with participants positioned in supine on a plinth. The anterior superior iliac spine and the lateral malleolus were identified by palpation and marked with a pen. The distance between the anterior superior iliac spine and lateral malleolus was measured using a tape measure. The measurement was performed three times and an average was recorded for each leg. A leg length discrepancy greater than 15 mm is considered as a risk factor for musculoskeletal injury [54]. Therefore, participants with a leg length discrepancy of greater than 15 mm were excluded from the study. The validity and reliability of this test has previously been established[54].

b) Q-Angle

The Q-angle was measured with participants positioned in standing. The anterior superior iliac spine, the midpoint of the patella and the tibial tuberosity were identified by palpation and marked with a pen. The Q-angle was measured as the angle between a line from the anterior superior iliac spine to the midpoint of the patella; and a line from the midpoint of the patella to the tibial tuberosity. The Q-angle was measured using a goniometer. The measurement was performed three times and an average was recorded for each leg. A Q-angle greater than 14° in males is considered as a risk factor for musculoskeletal injury[101]. Therefore, participants with a Q-angle of greater than 14° were excluded from the study. The validity and reliability of this test has previously been established[101].

3.3.1.4 Anthropometry

Body mass (kilograms) (kg) was recorded using a calibrated scale (Slimguide skinfold collection model: FAB12-1125). Stature (cm) was recorded using a stadiometer (Seca model, 206 Germany). Body fat was expressed as the sum of seven skinfolds (biceps, triceps, subscapular, suprailiac, calf, thigh and abdomen), as described by Ross and Marfell-Jones[113]. Body fat was also expressed as a percentage of body mass[41].

3.3.2 Online Training Log

Participants were required to keep an electronic training log for the 12-week study period (Appendix V). The training log recorded the following information: total running distance per week (km); total running duration per week in minutes; session RPE scores; weekly incidence of self-reported pain; BPI scores; and anatomical sites of pain in the lower limbs.

3.3.2.1 Weekly Training History

The average total distance covered per week for the total 12 weeks was recorded in the '*total distance'* column. The distance was recorded in kilometres. The total time taken to complete the distance covered was completed in the appropriate column. The time was recorded in minutes at the end of each week for the total 12 weeks of the study[22] (Appendix V).

3.3.2.2 Session Rate of Perceived Exertion

The session RPE was measured with the session RPE scale and was recorded in the *'RPE'* section of the online training log. The participants were asked to respond to the question *'on average, how hard were your training sessions this past week?'* This value was recorded on a scale at the end of each week, for a total of 12 weeks. This scale ranged from zero to ten where zero meant *'rest'* , one meant '*really easy'*, two meant '*easy*', three meant '*moderate*', four meant '*sort of hard'*, five meant '*hard*', seven meant '*really hard'*, nine meant '*really, really hard'* and ten meant '*just like my hardest race'*. The session RPE scale showed a rating of overall difficulty of the exercise performed (Appendix V and VIII). This scale translated the participants' perception of effort into a numerical score. The participants were required to complete the '*RPE*' section of the online training log 30 minutes after their last training session per week. The numerical score reflected the participants' global impression of the training sessions per week[40,44,48,80].

3.3.2.3 Brief Pain Inventory (Self-Reported Pain)

The BPI was a short questionnaire designed to assess the weekly incidence, nature, severity and impact of pain experienced with pain scores[33,74]. Participants reported whether they experienced any pain in their lower limbs during weekly training sessions by responding to the question '*Have you experienced any pain this week?*' This was recorded as weekly incidence (% of runners in each group) of self-reported pain. If pain was experienced, the participants were required to complete the body chart by indicating the specific areas on the body chart where pain was felt in the lower limbs (Appendix V and VII). These anatomical sites of pain were coded therefore participants recorded the specific codes for the areas which hurt the most (weekly anatomical sites of pain). Cumulative numbers of the anatomical sites of pain were then calculated per pain area. In addition, the participants completed the first four questions of the BPI. The runners were asked to complete the appropriate section of the online training log with the number from zero to ten which best represented the severity of pain felt in four different grades. Zero represented '*no pain'* and ten represented '*pain as bad as you can imagine'*.

The four grades included: '*pain at its worst in the last week*'; '*pain at its least in the last week*'; '*pain on average this week*'; and '*pain that you have right now*' (Appendix V and VII). A weekly pain severity score (mean score of the four questions) for each participant was calculated by the investigator at the end of the 12 week study period. The difference between weekly incidence of self-reported pain and pain severity scores is that weekly incidence of self-reported pain simply referred to whether the participants had weekly pain (yes or no) and if so, the pain severity score was calculated. This was a summative score of current pain, pain at its worse, least and average. This was then divided by four and a pain severity score was recorded. During analysis, only the pain severity score was analysed as it gives an overall score of pain severity[33,74].

3.3.3 Standard Testing

Standard testing was conducted at baseline, and at four, eight, and 12 weeks post-baseline testing. Outcome measures that were assessed included: injury incidence; calf endurance; hamstring and soleus complex muscle flexibility; lower limb muscle power; standing foot posture index; hallux plantarflexion and dorsiflexion ROM; and satisfaction with the type of running shoes and performance. There was one research assistant that helped at the familiarisation session as well as at the data collection sessions. The assistant recorded all of the data onto the data collection sheets.

3.3.3.1 Injury Incidence

Injury incidence was reported as the number of injuries sustained per runner in the 12 week period and was assessed using a detailed injury report form. The injury report form was more comprehensive than the training logbook, and was completed every four weeks at the standard testing sessions. The injury report form captured information regarding injury history, namely: date of injury; type of injury; location of injury; mechanism of injury; and training days missed were documented in the form[58]. Participants that sustained running related injuries during the 12 week study period were not required to perform further testing. The data from these participants were included for analysis as injury incidence was an important measure. Thus, a running related injury was defined as any reported muscle, joint or bone problem/injury of lower limb (ie. buttock, hip, thigh, knee, shin, calf, ankle, foot) resulting from running training that required the runner to miss at least one training day or a training session[58,105].

3.3.3.2 Calf Endurance

The calf raise test was used to assess the endurance of the calf musculotendinous unit in a weight bearing position[38,56]. The starting position for the test was barefoot single-leg standing with the knee extended. The ball of the foot was positioned on the step with the heel off the step. Participants were instructed to perform a heel raise into maximal plantarflexion range. This was then followed by slowly lowering the heel back downwards into the starting position. During testing, the knee of the leg being tested remained extended at all times. The heel raises were performed at a rate of one maximal plantarflexion/dorsiflexion range per second with no resting intervals. A metronome was used to provide the correct speed at which the raises were performed. The heel raises were video recorded (lateral view) to ensure that maximal plantarflexion ROM was achieved in each repetition. The test was terminated if participants did not achieve maximal plantarflexion ROM on three consecutive repetitions; or if participants could not maintain the required frequency of heel raises. The modified Borg scale was used to assess rate of perceived exertion during the test. The test was also discontinued if participants rated their rate of perceived exertion between 17 and 20 (‘*very hard’* to ‘*maximal exertion’*) (Appendix VI). Participants were also allowed to voluntarily discontinue the test at any time due to fatigue. The test was stopped if any participant met only one of these conditions. Participants received standard verbal encouragement to ensure maximal performance. Once the test was terminated, participants had a three minute rest period before repeating the test on the other leg. The video recordings were assessed three times to determine the total number of calf raises, and an average was recorded[38,56]. The reliability and validity of this test has previously been established[38,56,57].

3.3.3.3 Hamstring Muscle Flexibility

The active knee extension test was used to measure hamstring flexibility. Participants were positioned in supine on a plinth with the ankle of the test leg in a relaxed position. The non-test leg was strapped to the plinth with a velcro strap to stabilise the pelvis and to prevent flexion of the non-test leg during testing. A velcro strap was also positioned over the pelvis to increase stability. A stabilisation board that consisted of two vertical bars on either side of the plinth connected by a horizontal bar at 45 cm was used to ensure that the hip position of the test leg was maintained at 90° of hip flexion during the measurement (Figure 3.2). Participants were instructed to actively extend the knee while keeping the foot in a relaxed position to minimise the influence of the gastrocnemius muscle as well as neural tension in the lower limb. Participants were instructed to extend their knee until the onset of a stretch sensation was felt. When final extension was reached, the investigator supported the calf and measured the degree of knee extension. A goniometer was used to measure the popliteal angle[8,38,64,73,141].

The fulcrum was placed on the lateral epicondyle of the femur; the stationary arm was aligned with the lateral midline of the thigh, with the greater trochanter as a reference point; and the moving arm was aligned with the lateral midline of the fibula with the lateral malleolus as the reference point. Participants performed three repetitions on each leg, and an average was recorded[8,38,64,73,141]. The reliability and validity of this test has previously been established[8,38,64,73,141].


[redacted]

Figure 3.2: *Starting position of the active knee extension test.*

3.3.3.4 Calf Muscle Flexibility

The ankle lunge test was performed to measure the flexibility of the soleus complex. Participants were barefoot and were required to perform weight bearing dorsiflexion by lunging forward, with the knee beyond the toes. Participants positioned the foot so that a line drawn through the first toe and heel were aligned on a tape measure on the floor. The 0 cm point was positioned at the junction of the floor and wall. A vertical line was then drawn up the wall in line with the tape measure. The investigator held the participant’s heel to ensure contact was maintained with the floor at all times, and to manually lock the subtalar joint so that it remained in neutral throughout the test. Participants were instructed to lunge forward so that the knee touched the vertical line on the wall. The leg which was not being tested was permitted to rest on the floor. Participants were permitted to hold onto the wall for support if needed (Figure 3.3). Participants performed three repetitions on each leg, and an average distance from the tip of the first toe to the wall was recorded to the nearest 0.1 cm[8,64,123]. The reliability and validity of this test has previously been established[8,64,123].

Figure 3.3: *Ankle lunge test.*

3.3.3.5 Muscle Power: Vertical Jump Test

A bilateral, barefoot vertical jump from a stationary squat position was used to determine muscle power of the lower limbs. Standing reach height was determined while participants stood side-on against a wall and extended the arm closest to the wall maximally above the head. Participants were not permitted to lift their heels off the ground. The maximal height on the wall was marked with yellow talcum powder from the participants' fingertips. Standing reach height (cm) was measured with a tape measure. Before each jump and during testing, participants were verbally encouraged to jump as high and straight as possible. Each participant had their dominant hand painted with red talcum powder, which ensured their maximal vertical jump height was recorded on the wall. Participants were instructed to squat down to a knee angle of approximately 90°, while finger tips touched the floor. This was followed by a brief interval (2 s) during which the participants' squat position was standardised by the investigator. A quick visual check was conducted to make sure that each participant started in the correct position. This was then followed by a verbal instruction to commence the vertical jump. At the peak of the jump, participants touched the wall with their powdered hand. The use of arms during take-off was permitted, but no shuffling on feet was allowed. Muscle power was reflected as the difference between the standing reach height and the vertical jump height[3].

The vertical jump was performed three times and an average was recorded[3]. The reliability and validity of this test has previously been established[3].

3.3.3.6 Foot Posture: Foot Posture Index

The standing foot posture was measured using the foot posture index. Participants stood in a relaxed stance position with double limb support, and were instructed to stand still, look straight ahead and keep their arms at their sides. During the assessment, the investigator ensured that participants did not look around or swivel at any point. The foot posture index evaluates six criteria on each foot, namely: talar head palpation; supra- and infra-malleolar curvature; calcaneal frontal plane position; prominence in the region of the talonavicular joint; congruence of the medial longitudinal arch; and adduction/abduction of the fore-foot on the rear-foot. Each criterion was scored on a scale of -2, -1, 0, +1, or +2. (Appendix IX). The results were then combined into a summative score and categorised to define the type of foot posture as follows: highly supinated (-12 to -5); supinated (-4 to -1); neutral (0 to +5); pronated (+6 to +9); and highly pronated (10+) (Appendix IX). This test was performed once on each foot. The reliability and validity of this test has previously been established[92,106,115].

3.3.3.7 Hallux Range of Motion

Hallux plantarflexion and dorsiflexion ROM was measured passively using a hand-held goniometer. Participants were positioned in supine on a plinth, and were required to relax throughout the testing procedure. The goniometer was positioned with the fulcrum placed over the centre of the first metatarsophalangeal joint; the stationary arm was aligned with the proximal phalanx; and the moving arm was aligned with the shaft of the first metatarsal. The investigator passively dorsiflexed and plantarflexed the hallux of each foot to the end of range. End of range was reached once the hallux reached full range (bony end feel) and no pain was felt by the participant. Each measurement was performed three times on the right and left hallux, and an average was recorded. The reliability and validity of this test has previously been established[4,12,88].

3.3.3.8 Participants' Overall Satisfaction with the Type of Running Shoes, Training and Performance, Lower Limb Function and Comfort and Support: Satisfaction Questionnaire

A questionnaire (Appendix IV) was developed by the researcher, to assess the participants' satisfaction with the type of running shoes and performance. Each participant was required to complete this satisfaction questionnaire at zero, four, eight and 12 weeks of the study. The participants were required to answer each question that related to their satisfaction with the type of running shoes and performance, namely: training; injury status; performance; lower limb flexibility; lower limb muscle strength; comfort during running; the support offered from the running shoes; satisfaction with continuing to run in minimalist running shoes; and satisfaction with continuing to run in conventional running shoes (Appendix IV). This questionnaire was separated into six main sections. Overall satisfaction with the type of running shoes included question one. General satisfaction with training and performance included questions two to five. General satisfaction with lower limb function included questions six and seven. General satisfaction with comfort and support of shoes included questions eight to 11. Lastly, satisfaction with continuing to run in conventional or minimalist shoes included question 12. In addition, a total satisfaction score consisting of all the questions was calculated. The experimental and the control group each received a questionnaire in which only the last question differed as the experimental group ran in minimalist running shoes and the control group ran in conventional running shoes (Appendix IV). The remaining questions were identical. The questionnaire consisted of twelve closed-ended questions. Each question consisted of the question and response categories[59]. The response categories consisted of a five point ordinal Likert Scale. This was represented by a numerical value. The analysis of the satisfaction questionnaire data is described in Section 3.3.6 (page 71).

a) Validity and Feasibility of the Satisfaction Questionnaire

The questionnaire was developed and reviewed by a panel of experts to ensure content and construct validity. The expert validators included a local sport physician, sport biokineticist as well as a sport physiotherapist with special interests in endurance running. The expert validators were selected based on their expertise and reputation in the field of endurance sport, especially running. Three validators were chosen nationally. Once ethical approval was given, the validators were contacted requesting their assistance in validating the questionnaire. The validators were asked to comment individually on the relevance and importance of the questions within the questionnaire and whether they were clear and easy to understand. In addition, the validators were able to add any section or questions that they felt may be absent from the questionnaire that may contribute to the study. The validators were asked to complete the review of the questionnaire within a four week period.

The researcher and supervisors reviewed and consolidated the feedback from the three validators, and compiled an updated version of the questionnaire. The validators were then contacted if there was conflicting feedback and a conference call was held to reach consensus. Once changes had been completed, the questionnaire was returned to all validators for approval as well as to ensure consensus. The validators were asked to perform this final review within a two week period. Feasibility of the questionnaire was established in a feasibility study consisting of ten participants who met the study's inclusion criteria. Participants were asked to comment on the comprehension of the questions and the ease of completion of the questionnaire. All necessary adjustments were made to the questionnaire prior to data collection. Participants' questionnaires from the feasibility study were not included in data analysis.

3.3.4 Four Week Training Programme

Participants in the experimental and control groups were required to complete a four week training programme that commenced after baseline testing. The primary purpose of the training programme was to allow participants in the experimental group to become accustomed to running in minimalist shoes, and to reduce the risk of injury associated with running in unfamiliar shoes. Participants in the experimental group were required to complete all elements of the training programme, namely a progressive increase in walking and running, and hopping training (calf muscle training) as shown in Table 3.1[22].

Table 3.1: *Four week training programme that was completed by the experimental group.*

	Run (min)	Reps	Walk (mins)	Hop (number)	Days per week
Week 1	10	2	5	30	4
Week 2	15	2	5	40	4
Week 3	35	1	0	55	4
Week 4	45	1	0	70	4

(Adapted from Bredeweg et al[22])

Participants in the control group were required to complete the hopping training (calf muscle training) only[22], as shown in Table 3.2, in addition to their regular running training. The control group were also required to perform hopping training to ensure that both the experimental and control groups were exposed to similar, unaccustomed loading of the calf musculature.

Table 3.2: *Hopping sessions (calf muscle training) that were completed by the control group.*

	Hop (number)	Days per week
Week 1	30	4
Week 2	40	4
Week 3	55	4
Week 4	70	4

(Adapted from Bredeweg et al[22]*)*

As the runners in the experimental group were experienced long distance runners, the training programme commenced with ten minutes of running in the minimalist shoes. This was followed by five minutes of walking, then another session of ten minutes of running. Participants in the experimental group were required to run and walk for the first two weeks of the training programme; thereafter running was permitted without walking. The hopping (calf muscle training) sessions were performed after the walking and running components of the programme had been completed. Participants performed submaximal two-legged hopping four times per week. Participants were required to stand in a relaxed standing position. A distance of approximately 30 cm between the left and right feet was maintained during the hops. Participants were instructed to perform small jumps while the forefeet almost kept contact with the ground[22,23]. Participants in the control group performed the hopping sessions immediately on completion of their regular running training. There was a progressive increase in training load over the four week training programme (Tables 3.1 and 3.2). Compliance with the four week training programme was monitored via email. Participants were sent bi-weekly email reminders that included the weekly training schedule, as well as reminders regarding compliance with the training programme. Participants also completed a compliance checklist at the four week standard testing session (Appendix XI).

3.3.5 Reliability Study

A reliability study was conducted prior to testing to assess the intra-rater reliability of the anthropometric measurements and standard testing; and to determine the feasibility of the testing procedure. A sample of convenience was used and six participants that met the inclusion criteria for this study volunteered to take part in the reliability study. Firstly, a trial of the familiarisation session was conducted to determine the feasibility of this procedure. Anthropometric intra-rater reliability testing (body mass, stature, sum of seven skinfolds) was carried out in addition to intra-rater reliability testing to determine the reliability of the foot posture index test on both lower limbs.

The intra-rater reliability was also determined for the hand-held goniometric measurement of the popliteal angle (active knee extension test, hamstring flexibility), as well as hallux plantarflexion and dorsiflexion ROM on both lower limbs. Lastly, the intra-rater reliability was conducted on the ankle lunge test that used a tape measure to measure calf flexibility on both lower limbs. Week one of the four week training programme, the satisfaction questionnaire and the online training log formed part of the reliability study (feasibility testing). This reliability study took place over five days. The data from the reliability study were not included in the primary research study. The results of the reliability study are presented in Appendix XII.

3.3.6 Statistical Analyses

Data were analysed using Statistica Software (StatSoft, Inc. 2004. STATISTICA, Data Analysis Software System, Version 11, www.statsoft.com). There were no missing data in this study, as all participants attended each testing session. The Shapiro-Wilkes test was used to determine whether data were normally distributed. Differences in screening tests, descriptive variables, including injury incidence, between the experimental group and control group were assessed using an independent t-test. General sports activities and weekly incidence of self-reported pain were assessed using Chi-squared tests and frequency tables.

Statistical significance for the two main effects of group and time, and the interaction (group x time) of variables (calf endurance, muscle flexibility, muscle power, foot posture index, hallux ROM, training data, session RPE, pain severity scores and the satisfaction questionnaire data) were assessed using an analysis of variance (ANOVA) with repeated measures. An unequal HSD post-hoc test was performed where necessary. A Mann-Whitney U test was used to assess differences in the total anatomical sites of pain between groups. Cumulative numbers were used to represent anatomical sites of pain on the body chart. A Friedman's ANOVA and Kendall's concordance was used to assess differences in the pain scores within groups over time.

Parametric statistics were used to analyse the Likert scale satisfaction questionnaire data. The internal consistency of the satisfaction questionnaire data was assessed using SPSS (SPSS Software, Inc, IBM SPSS Statistics, Statistical Analysis Software Package, Version 21, www-01.ibm.com/software/analytics/spss/) (Appendix XVIII). Cronbach's Alpha was 0.607 (week 0), 0.885 (week 4), 0.838 (week 8), and 0.860 (week 12). A high level of internal consistency is considered as Cronbach's Alpha ≥ 0.7. These high levels of internal consistency support the use of parametric statistics to analyse satisfaction responses.

Although there is some controversy surrounding the preferred method of analysis for Likert scale data, current literature supports the use of parametric techniques with data that do not necessarily represent equal-interval values, particularly when the number of categories on the scale is five or more, as in this study[69]. All data are presented as the mean ± SD. Statistical significance was accepted as $p < 0.05$.

3.3.7 Ethical Considerations

The study was granted ethical approval from the UCT, Faculty of Health Science Human Research Ethics Committee (HREC REF: 258/2012) (Appendix XIII). This study adhered to the ethical principles outlined in the Declaration of Helsinki (Seoul version, 2008). Once ethical approval was granted, informed consent forms (Appendix I) were given to participants. The purpose, testing procedures and possible risks and benefits of the study were explained to the participants. The participants had the right to withdraw from the study at any given time. All data were regarded as confidential. This was achieved by using a coding system, whereby each participant's personal information was linked to a code. The document containing participant's codes and personal information was held in a locked filing cabinet by an independent auditor for the duration of the study. Furthermore, participants will not be identified in any publications that may arise from this thesis. Participants were advised regarding treatment if an injury was sustained during the study period, and where necessary, participants were referred to an appropriate health professional. In addition, participants were provided with an information sheet that included individual participant feedback (Appendix XVII). Furthermore each participant received an email that contained the results of the study. The results of the study will be disseminated and published in a peer-reviewed journal.

3.3.7.1 Risks to Participants

a) Training Log, Intrinsic Screening Tests, Injury Report Form, Satisfaction Questionnaire, Anthropometry, Muscle Pain Measurements, Session RPE and Foot Posture Index Test

There were no risks associated with completing the training log, intrinsic screening tests, injury report form and satisfaction questionnaire. There were also no risks associated with mass, stature, muscle pain (including weekly self-reported pain measurements), and session RPE measurements or the foot posture index assessment. Participants may have experienced minor discomfort during the measurement of skinfold thickness from the callipers gripping skinfolds, however this discomfort was minor and transient.

b) Calf Raise Test, Vertical Jump Test, Hallux Range of Motion and Flexibility Tests

The calf raise test involved repeated submaximal gastrocnemius and soleus contractions. The vertical jump test involved maximal quadriceps contractions. The risks of these contractions were similar to that of performing unaccustomed exercise including painful and stiff muscles. A warm-up was conducted prior to testing to minimise these possible risks. The hallux ROM test involved moving the metatarsophalangeal joint to end of range. This may have posed a risk of possible over stretch of the muscles around this joint. The flexibility tests involved moving the ankle joint and hamstrings up until the onset of a stretch sensation was felt. This may have posed a risk of a possible over stretch of the muscles around the ankle joint and the hamstrings. These risks were minimised by familiarising participants prior to testing and by carefully instructing participants to stop the movements at the onset of a stretch sensation. In addition, if participants sustained an injury during the 12 week study period, they were not required to perform any further testing. These participants were referred for assessment and treatment post injury.

c) Four week Training Programme

Participants in both the experimental and control groups may have been exposed to the risk of sustaining a running related injury during the four week training programme as muscles were conditioned during this programme. These risks were minimised by familiarising the participants with the training programme and hopping sessions (calf muscle training) prior to the commencement of the study. In addition, the main purpose of the training programme was to allow participants in the experimental group to become accustomed to running in minimalist shoes, and to reduce the risk of injury associated with running in unfamiliar shoes. There is also an inherent risk of injury associated with endurance running. Participants were asked to avoid strenuous training and competition for the duration of the study period to minimise the risk of running related injuries.

3.3.7.2 Benefits to Participants

The aim of this randomised clinical trial over 12 weeks was to determine if the gradual transition (accompanied by calf muscle training), from conventional to minimalist running shoes 1) increased the risk of lower limb pain or injury and 2) improved lower limb muscle function (endurance, flexibility and power) in experienced distance runners. In addition, the effects of the transition on runner satisfaction were studied. Participants were provided with an information sheet that included individual participant feedback (Appendix XVII). In addition, each participant received an email that contained the results of the study.

Participants in the experimental group were provided with a pair of minimalist running shoes, and participants in the control group received a discount from a local shoe manufacturer if they purchased a pair of minimalist running shoes on completion of the study.

3.4 Results

3.4.1 Participants

Thirty-two participants were recruited for this study. Thirty-one participants were eligible for inclusion in the study. One participant was excluded (as the participant was not able to commit fully to the study protocol). In addition, one participant withdrew at week six during the study period due to personal reasons. One other participant sustained a cycling injury in week 11 and was also excluded from the study. Furthermore, one participant in the experimental group sustained a running related injury in week four. This participant did not continue with further testing for the remainder of the study period. In addition, one participant in the control group sustained a running related injury in week 12. This did not affect further testing as this was the final week of the study. Both of these participants' data were included in data analysis. Therefore, the experimental and control groups consisted of fifteen and fourteen participants respectively. The study sample is summarised in Figure 3.4.

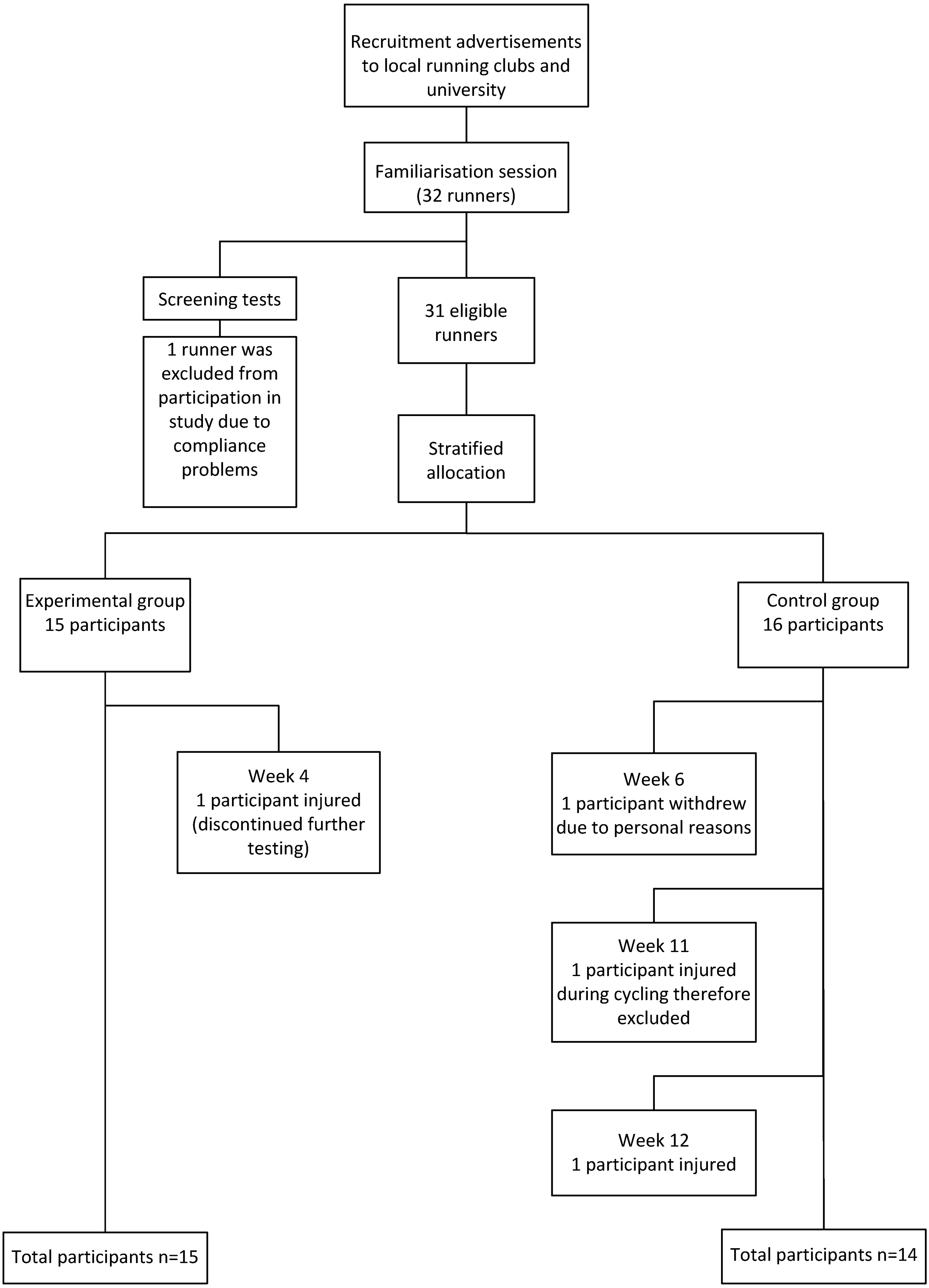


Figure 3.4: *Summary of study sample.*

3.4.2 Screening Tests

The results of the LLD and Q-angle screening tests for participants in the experimental and control group are summarised in Table 3.3. All LLD and Q-angle screening tests were negative for participants in the experimental and control groups. There were no significant differences between groups for these two screening tests.

Table 3.3: *Summary of results from the LLD (cm) and Q-angle (°) screening tests for participants in the experimental (n = 15) and control groups (n = 14). Data are expressed as mean ± SD.*

Screening test	Experimental	Control
LLD (cm)	0.0 ± 0.5	0.2 ± 0.6
Left Q-angle (°)	11.3 ± 1.7	11.4 ± 2.1
Right Q-angle (°)	11.4 ± 1.6	10.6 ± 2.2

3.4.3 Descriptive Characteristics

The descriptive characteristics of participants are shown in Table 3.4.There were no significant differences between groups for any of these variables.

Table 3.4: *Descriptive characteristics of participants in the experimental (n = 15) and control (n = 14) groups. Data are expressed as mean ± SD.*

Variable	Experimental	Control
Age (years)	32.9 ± 7.5	33.3 ± 8.3
Mass (kg)	78.9 ± 8.8	80.5 ± 10.2
Stature (m)	1.8 ± 0.1	1.8 ± 0.1
Body mass index (kg.m^{-2})	24.7 ± 2.4	25.3 ± 2.7
Sum of 7 skinfolds (mm)	84.8 ± 25.3	88.9 ± 25.7
Body fat (%)	18.6 ± 4.1	19.8 ± 4.3
Lean body mass (kg)	64.0 ± 5.1	64.5 ± 8.2

The training characteristics of participants are shown in Table 3.5. There were no significant differences in training characteristics between groups.

Table 3.5: *Training characteristics of participants in the experimental (n = 15) and control (n = 14) groups. Data are expressed as mean ± SD.*

Variable	Experimental	Control
Running experience (years)	9.1 ± 6.9	7.4 ± 5.4
Weekly training distance (km)	49.0 ± 6.6	48.9 ± 10.4
Best time for 10 km (minutes) †	41.4 ± 5.2	42.3 ± 5.4
Best time for 21.1 km (minutes) ††	95.0 ± 15.1	99.3 ± 11.9

† n = 4 missing (experimental group: n = 2; control group n = 2)

† † n = 2 missing (experimental group)

The general sports activities of participants in the experimental and control groups are shown in Table 3.6. There were no significant differences in training characteristics with regards to different sports and the number of training sessions per week between groups. The numbers of training sessions per week were in addition to running training. The experimental group took part in 4.4 ± 3.8 training sessions per week, and the control group took part in 4.3 ± 3.5 training sessions per week for different sporting activities.

Table 3.6: *General sports activities of participants in the experimental (n = 15) and control (n =14) groups. Data are expressed as numbers and percentages.*

Sports	Experimental n (%)	Control n (%)
Swimming	6 (40)	7 (50)
Cycling	7 (47)	7 (50)
Golf	4 (27)	3 (21)
Tennis	1 (7)	0 (0)
Athletics	2 (13)	1 (7)
Canoeing	1 (7)	0 (0)
Resistance training	3 (20)	3 (21)
Squash	2 (13)	2 (14)
Walking	1 (7)	1 (7)
Soccer	1 (7)	0 (0)
Hiking	0 (0)	1 (7)

3.4.4 Weekly Training Data, Weekly Rate of Perceived Exertion Scores and Weekly Self-Reported Pain

Participants were required to record weekly training data, rate of perceived exertion scores and weekly incidence of self-reported pain during training each week. These data were recorded in an online training log for the duration of the study, and are presented in the following section.

3.4.4.1 Weekly Running Distance and Duration of Running

Table 3.7 shows the weekly running distance and duration of running of participants in the experimental and control groups. There were no significant differences in weekly running distance and duration of running between groups or over time.

Table 3.7: *Weekly running distance (km) and duration of running (minutes) of participants in the experimental (n = 15) and control (n =14) groups. Weekly running distance and duration of running were recorded from week 0 to week 12. Data are expressed as mean ± SD.*

	Running Distance (km)		**Duration of Running (minutes)**	
Week	**Experimental**	**Control**	**Experimental**	**Control**
0	42.2 ± 16.8	37.1 ± 21.1	226.1 ± 105.2	209.4 ± 131.6
1 $^{\Psi}$	23.9 ± 7.4	37.5 ± 12.4	119.9 ± 44.8	191.4 ± 64.9
2 $^{\Psi}$	28.5 ± 4.4	35.6 ± 23.0	151.5 ± 34.9	183.1 ± 112.5
3 $^{\Psi}$	33.1 ± 11.7	35.8 ± 22.5	154.5 ± 56.1	194.2 ± 114.2
4 $^{\Psi}$	41.5 ± 16.7	39.9 ± 19.6	193.9 ± 57.2	227.4 ± 128.3
5	38.2 ± 15.2	31.1 ± 21.6	206.3 ± 100.1	158.5 ± 103.6
6	36.7 ± 17.2	40.0 ± 30.0	192.8 ± 100.6	214.1 ± 152.2
7	38.8 ± 17.6	44.0 ± 32.6	190.3 ± 81.8	217.4 ± 152.1
8	34.1 ± 22.7	42.7 ± 19.5	197.0 ± 165.0	233.8 ± 105.1
9	32.5 ± 16.4	36.4 ± 18.7	167.6 ± 89.0	184.6 ± 85.8
10	38.3 ± 11.1	40.4 ± 22.4	192.2 ± 64.8	203.9 ± 108.6
11	33.1 ± 20.8	39.4 ± 20.6	166.4 ± 105.8	220.4 ± 114.9
12	33.7 ± 16.9	36.5 ± 18.8	179.6 ± 95.5	188.3 ± 84.9

$^{\Psi}$ Four week training programme

In addition, compliance with the four week training programme was monitored. There was 100% compliance between participants in both the experimental and control groups with the four week training programme according to the compliance checklist (Appendix XI).

3.4.4.2 Rate of Perceived Exertion Scores

Table 3.8 shows the weekly rate of perceived exertion scores of participants in the experimental and control groups. There were no significant differences in rate of perceived exertion scores between groups or over time.

Table 3.8: *Weekly rate of perceived exertion scores of participants in the experimental (n = 15) and control (n =14) groups. Weekly rate of perceived exertion scores were recorded from week 0 to week 12. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	3.2 ± 1.4	3.6 ± 2.1
1 $^{\Psi}$	3.7 ± 1.7	3.1 ± 0.9
2 $^{\Psi}$	3.7 ± 0.7	3.0 ± 1.2
3 $^{\Psi}$	3.8 ± 1.3	3.3 ± 1.1
4 $^{\Psi}$	4.1 ± 1.6	3.1 ± 1.5
5	3.2 ± 1.3	2.7 ± 1.6
6	3.1 ± 1.1	3.1 ± 1.4
7	3.5 ± 1.2	2.9 ± 1.6
8	3.1 ± 1.7	3.5 ± 1.8
9	3.4 ± 1.8	3.6 ± 1.8
10	3.8 ± 1.3	3.9 ± 2.7
11	3.1 ± 1.6	4.1 ± 2.2
12	2.9 ± 1.7	2.9 ± 1.8

$^{\Psi}$ Four week training programme

3.4.4.3 Self-Reported Pain

Self-reported pain included weekly incidence of self-reported pain, pain severity scores, anatomical sites of pain as well as cumulative numbers of anatomical sites of pain.

a) Weekly Incidence of Self-Reported Pain

Differences in weekly incidence (% of runners in each group) of self-reported pain for participants in the experimental and control groups are shown in Figure 3.5. There were no significant differences in weekly incidence of self-reported pain between groups or over time.

Figure 3.5: *Weekly incidence (% of runners in each group) of self-reported pain of participants in the experimental (n = 15) and control (n = 14) groups. Weekly incidence of self-reported pain was recorded from week 0 to week 12. Data are expressed as percentages.*

b) Pain Severity Scores

Table 3.9 shows the weekly pain severity scores of participants in the experimental and control groups. The difference between weekly incidence of self-reported pain and pain severity scores is that weekly incidence of self-reported pain simply referred to whether the participants had weekly pain (yes or no) and if so, the pain severity score was calculated. This was a summative score of current pain, pain at its worse, least and average. This was then divided by four and a pain severity score was recorded. There were no significant differences in pain severity scores between groups or over time.

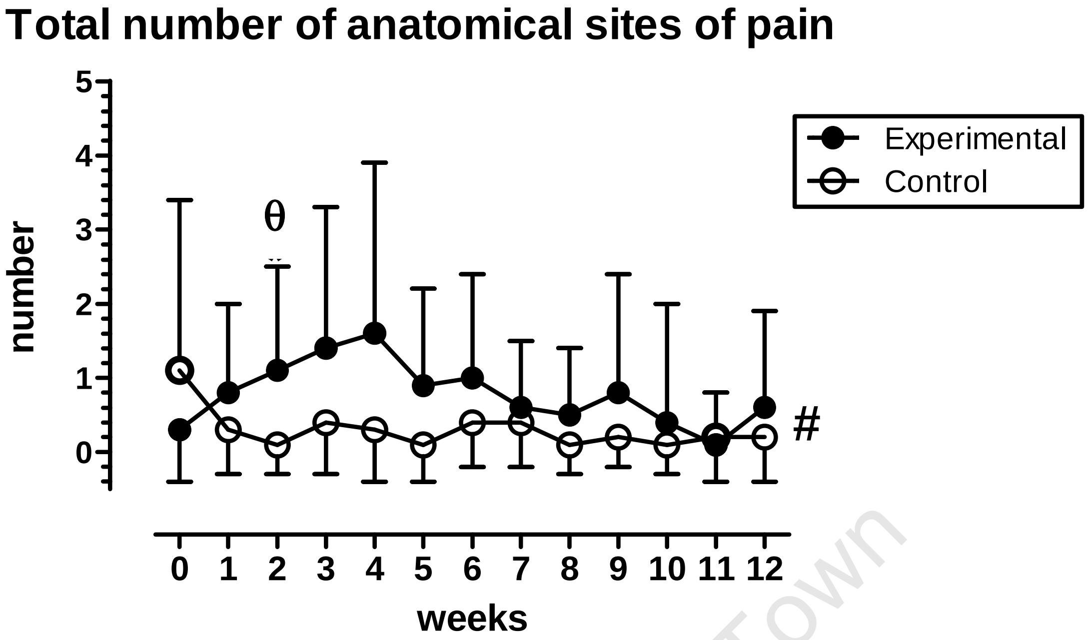
Table 3.9: *Weekly pain severity scores of participants in the experimental (n = 15) and control (n =14) groups. Weekly pain severity scores were recorded from week 0 to week 12. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	0.3 ± 0.4	1.0 ± 1.8
1$^{\Psi}$	0.7 ± 0.9	0.8 ± 1.0
2$^{\Psi}$	0.7 ± 0.8	0.1 ± 0.3
3$^{\Psi}$	1.2 ± 1.6	0.6 ± 1.0
4$^{\Psi}$	1.3 ± 1.6	0.8 ± 1.7
5	0.9 ± 1.1	1.0 ± 2.1
6	0.9 ± 0.8	0.8 ± 1.4
7	1.2 ± 1.5	1.4 ± 2.3
8	0.8 ± 1.0	0.7 ± 1.6
9	0.6 ± 0.9	0.9 ± 1.8
10	0.5 ± 0.9	1.1 ± 2.0
11	0.3 ± 0.6	0.8 ± 1.8
12	0.8 ± 1.5	0.5 ± 1.3

$^{\Psi}$ Four week training programme

c) Anatomical Sites of Pain

The total number of anatomical sites of pain per week that were reported by participants in the experimental and control groups are shown in Figure 3.6. There was a significant interaction between groups over time ($F_{(12, 312)}$ = 1.989; p = 0.025) in the total number of anatomical sites of pain reported per week. The experimental group reported a significantly higher number of anatomical sites of pain at week two, compared to the control group (p = 0.04).



Significant differences:

interaction of group x time (p = 0.025)

θ experimental group week 2 versus control group week 2 (p = 0.04)

Figure 3.6: *Weekly total number of anatomical sites of pain of participants in the experimental (n = 15) and control (n =14) groups. Weekly total number of anatomical sites of pain was recorded from week 0 to week 12. Data are expressed as mean ± SD.*

Anatomical sites of pain that were reported from week zero to week 12 are shown in Figures 3.7 (anterior anatomical sites of pain) and 3.8 (posterior anatomical sites of pain) respectively. These were recorded as cumulative numbers per pain area.

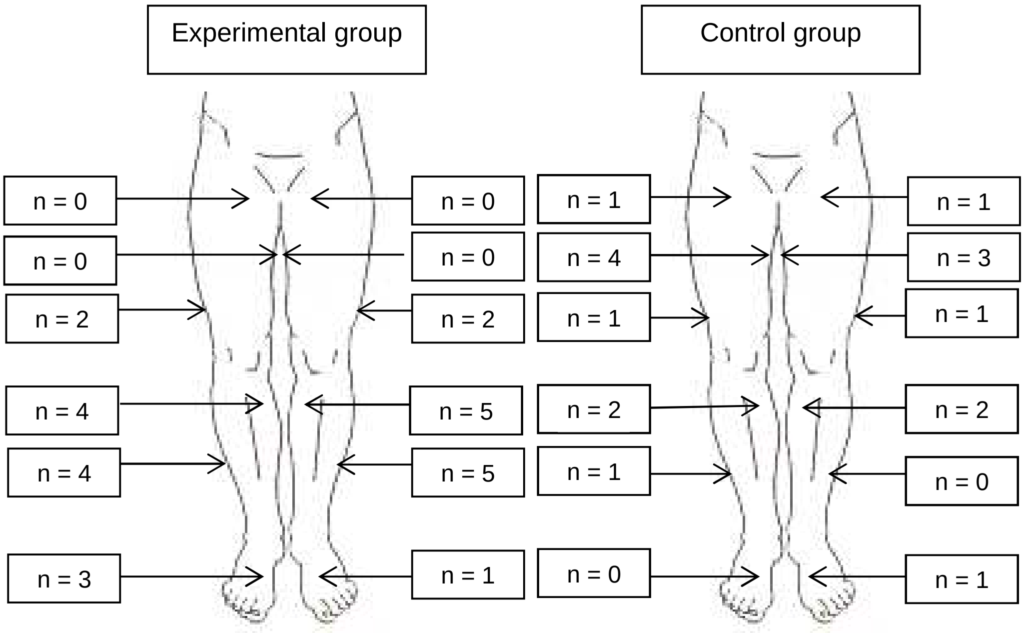


Figure 3.7: *Cumulative numbers of anterior anatomical sites of pain (numbers) of participants in the experimental (n = 15) and control (n = 14) group. Cumulative numbers of anatomical sites of pain were recorded from week 0 to week 12. Data are expressed as numbers.*

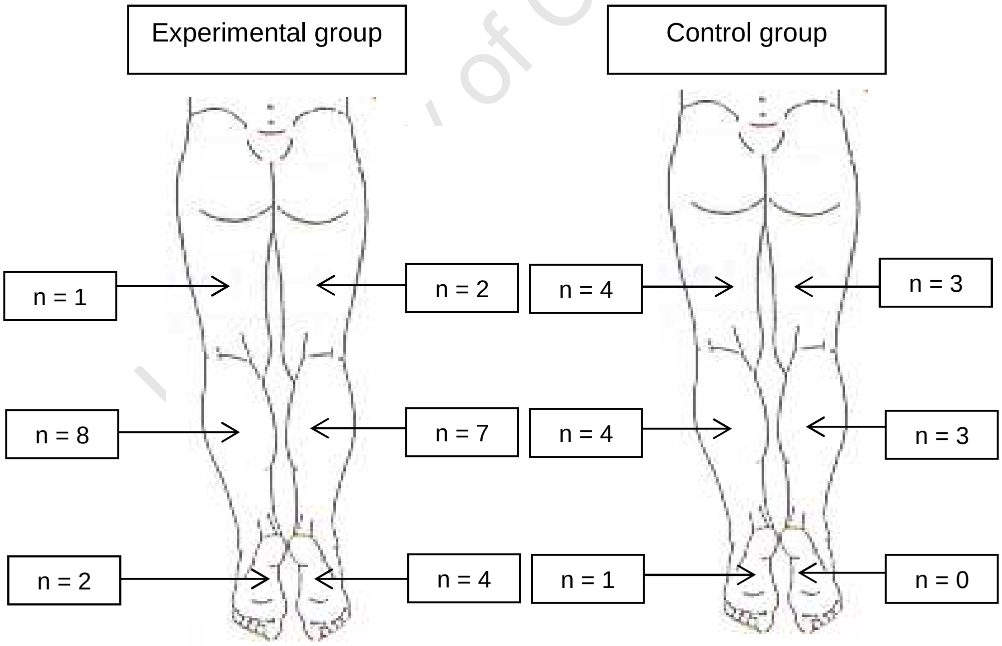


Figure 3.8: *Cumulative numbers of posterior anatomical sites of pain (numbers) of participants in the experimental (n = 15) and control (n = 14) groups. Cumulative numbers of anatomical sites of pain were recorded from week 0 to week 12. Data are expressed as numbers.*

3.4.5 Injury Incidence

The total incidence of injury over the 12 week study period for both groups was two (6.9%). Only one participant in each group reported a running related injury during the study period. There were no significant differences between groups or over time in lower limb injury incidence over the 12 week study period. One participant got injured in week four in the experimental group in two different anatomical sites of pain (Figure 3.9). The site of injury was the right lateral and posterior calf. This participant missed a total of seven days of training due to the injury. In addition, one participant got injured in week 12 in the control group in only one anatomical site of pain (Figure 3.9). The site of injury was the left lateral calf. This participant missed a total of seven days of training due to the injury.

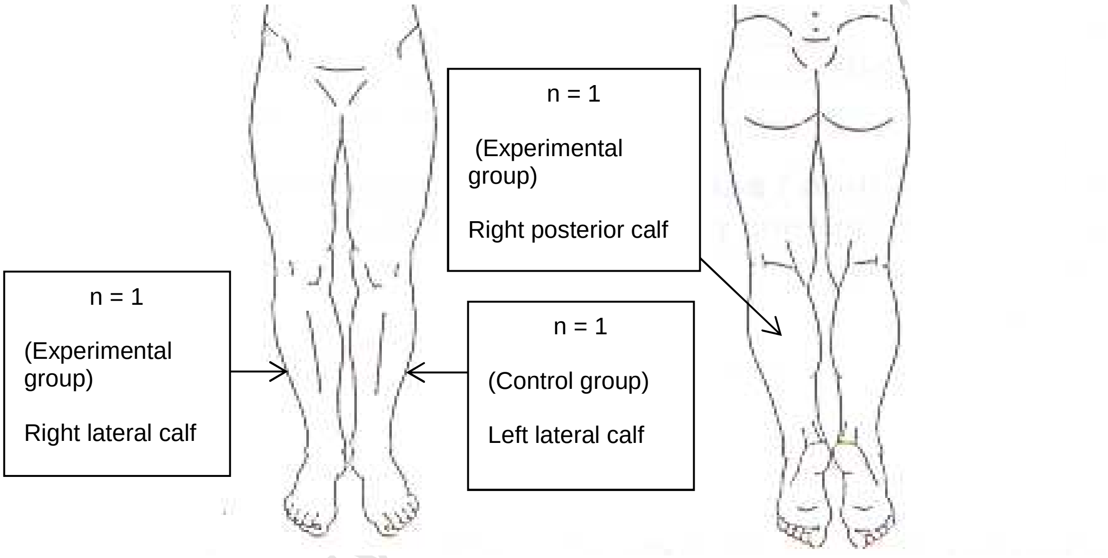
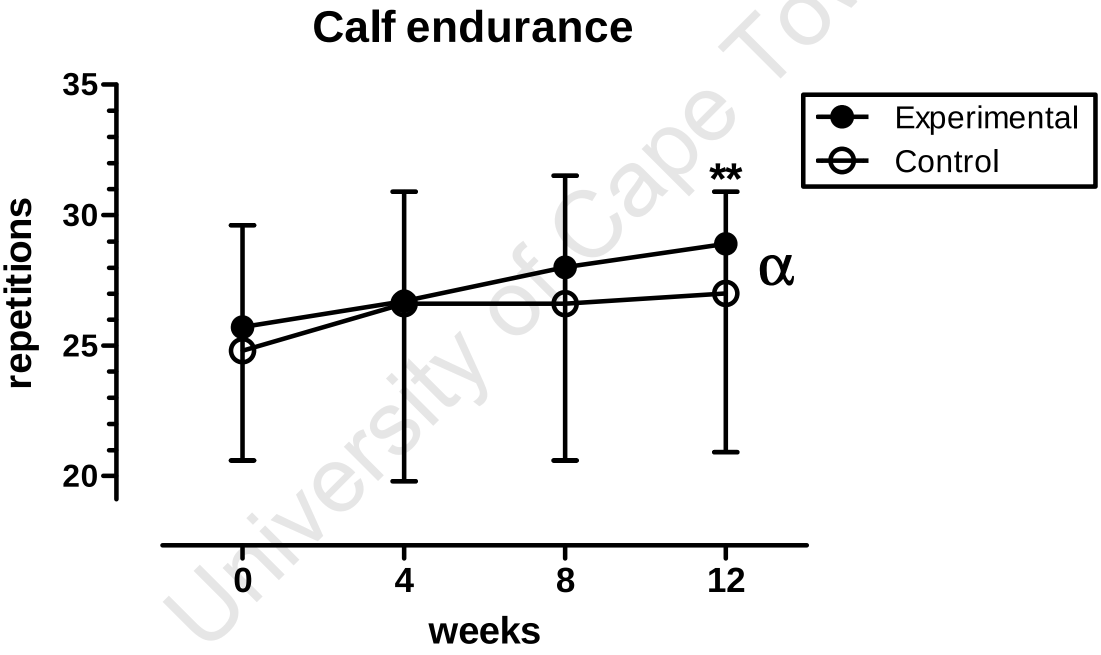


Figure 3.9: *Cumulative numbers of anterior and posterior anatomical sites of pain (numbers) of injured participants in the experimental (n = 15) and control (n = 14) groups. Cumulative numbers of anatomical sites of pain were recorded from week 0 to week 12. Injury incidence tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as numbers.*

3.4.6 Calf Endurance

Average calf endurance of participants in the experimental and control groups is shown in Figure 3.10. There were no significant differences in left, right or average calf endurance between groups. However, there were significant differences in the measurement over time for left calf endurance ($F_{(3,78)} = 4.826$; $p = 0.004$) and average calf endurance ($F_{(3,78)} = 4.270$; $p = 0.008$) (Figure 3.10). There were significant improvements in left calf endurance at week eight ($p = 0.043$) and week 12 ($p = 0.003$), compared to week zero (Appendix XV). In addition, average calf endurance improved significantly at week 12, compared to week zero ($p = 0.005$) (Figure 3.10). There were no significant differences in right calf endurance over time.



Significant differences:

α main effect of time ($p = 0.008$)

** week 12 versus week 0 ($p = 0.005$)

Figure 3.10: *Average calf endurance (number of repetitions) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

3.4.7 Hamstring Muscle Flexibility

The hamstring muscle flexibility of participants in the experimental and control groups is shown in Table 3.10. There were no significant differences in hamstring flexibility between groups or over time.

Table 3.10: *Hamstring muscle flexibility (°) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	**Experimental**			**Control**		
	Left	**Right**	**Average**	**Left**	**Right**	**Average**
0	151.6 ± 9.1	151.9 ± 10.8	151.7 ± 9.8	149.9 ± 11.7	150.1 ± 11.9	150.0 ± 11.5
4	152.4 ± 10.6	152.3 ± 8.9	152.3 ± 9.6	151.2 ± 10.5	150.9 ± 10.8	151.0 ± 10.6
8	152.9 ± 10.1	152.1 ± 8.5	152.5 ± 9.3	151.5 ± 10.2	150.5 ± 11.0	151.0 ± 10.4
12	152.2 ± 10.4	151.9 ± 8.8	152.1 ± 9.5	151.9 ± 10.3	151.4 ± 11.2	151.7 ± 10.6

3.4.8 Calf Muscle Flexibility

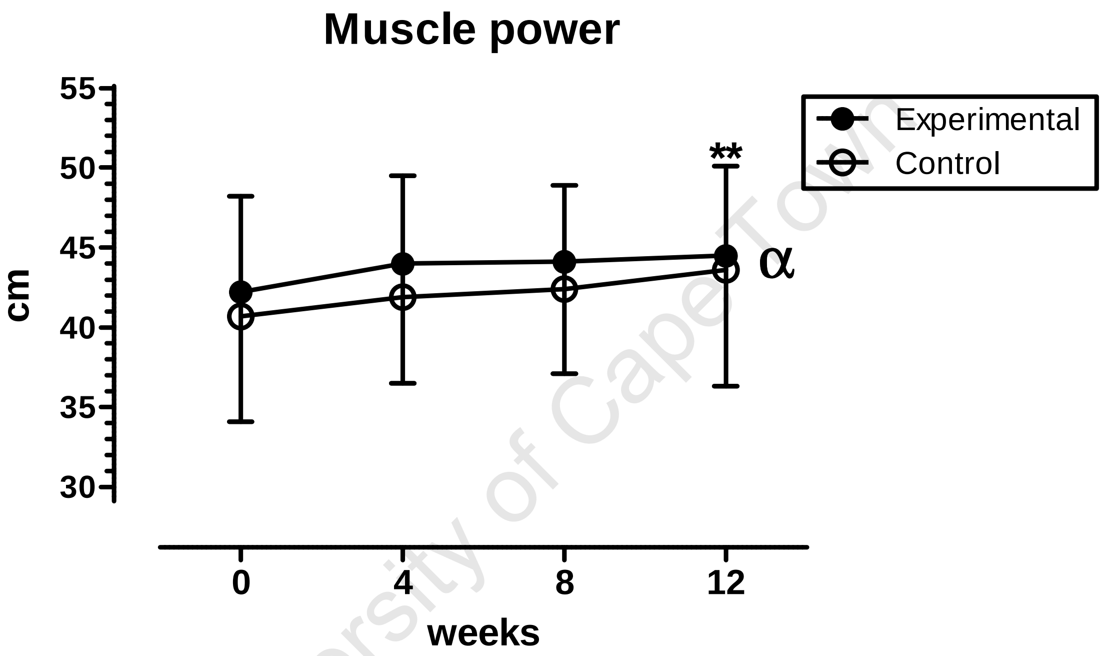
The calf muscle flexibility of participants in the experimental and control groups is shown in Table 3.11. There were no significant differences in calf muscle flexibility between groups or over time.

Table 3.11: *Calf muscle flexibility (cm) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	**Experimental**			**Control**		
	Left	**Right**	**Average**	**Left**	**Right**	**Average**
0	9.8 ± 3.6	10.0 ± 3.8	9.9 ± 3.6	9.9 ± 2.4	9.9 ± 2.3	9.9 ± 2.2
4	9.7 ± 3.7	10.1 ± 3.9	9.9 ± 3.7	9.8 ± 2.3	10.0 ± 2.5	9.9 ± 2.3
8	9.9 ± 3.6	10.1 ± 3.8	10.0 ± 3.6	9.9 ± 2.4	10.1 ± 2.7	10.0 ± 2.5
12	9.9 ± 3.5	10.1 ± 3.9	10.0 ± 3.6	10.0 ± 2.5	10.4 ± 2.9	10.2 ± 2.6

3.4.9 Lower Limb Muscle Power

The lower limb muscle power of participants in the experimental and control groups is shown in Figure 3.11. There were no significant differences between groups for lower limb muscle power, whereas there was a significant difference in the measurement over time ($F_{(3,\ 78)} = 4.717$; $p = 0.045$). Lower limb muscle power improved significantly at week 12 compared to week zero ($p = 0.002$).



Significant differences:

α main effect of time (p = 0.045)

**week 12 versus week 0 (p = 0.002)

Figure 3.11: *Average lower limb muscle power (cm) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

3.4.10 Foot Posture Index

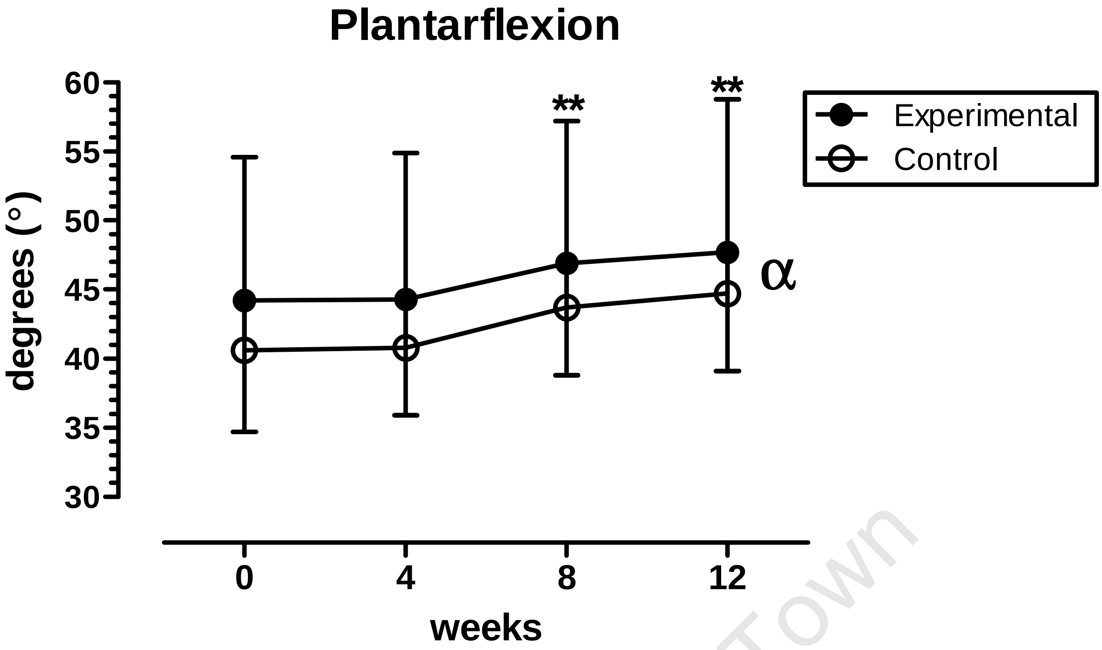
The foot posture index scores of participants in the experimental and control groups are shown in Table 3.12. There were no significant differences in foot posture index scores between groups or over time.

Table 3.12: *Foot posture index scores of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	**Experimental**			**Control**		
	Left	**Right**	**Average**	**Left**	**Right**	**Average**
0	3.7 ± 3.0	4.5 ± 3.6	4.1 ± 3.1	4.4 ± 2.5	5.1 ± 2.5	4.7 ± 2.3
4	3.9 ± 2.8	4.7 ± 3.6	4.3 ± 3.1	3.9 ± 2.0	5.1 ± 1.7	4.5 ± 1.8
8	3.9 ± 3.0	4.8 ± 3.6	4.3 ± 3.3	4.2 ± 2.9	5.4 ± 1.9	4.8 ± 2.3
12	4.1 ± 3.0	4.9 ± 3.7	4.5 ± 3.3	5.4 ± 1.8	3.9 ± 2.4	4.6 ± 2.0

3.4.11 Hallux Plantarflexion Range of Motion

Average hallux plantarflexion ROM of participants in the experimental and control groups is shown in Figure 3.12. There were no significant differences between groups for left, right and average hallux plantarflexion ROM, whereas there was a significant difference over time for left hallux plantarflexion ROM ($F_{(3, 78)}$ = 9.511; p = 0.00002), right hallux plantarflexion ROM ($F_{(3,78)}$ = 10.882; p = 0.00001), and average hallux plantarflexion ROM ($F_{(3,78)}$ = 15.704; p = 0.00001) (Figure 3.12) (Appendix XV). Left hallux plantarflexion ROM improved significantly at week 12 compared to week zero (p = 0.005); and at week eight (p = 0.024) and week 12 (p = 0.0002), compared to week four (Appendix XV). Right hallux plantarflexion ROM improved significantly at week eight (p = 0.0002) and week 12 (p = 0.0002), compared to week zero; and at week eight (p = 0.014) and week 12 (p = 0.01), compared to week four (Appendix XV). Average hallux plantarflexion ROM improved significantly at week eight (p = 0.0008) and week 12 (p = 0.0001), compared to week zero; and at week eight (p = 0.0009) and week 12 (p = 0.0002), compared to week four (Figure 3.12).



Significant differences:

α main effect of time (p = 0.00001)

** week 8 versus week 0 (p = 0.0008)

** week 12 versus week 0 (p = 0.0001)

** week 8 versus week 4 (p = 0.0009)

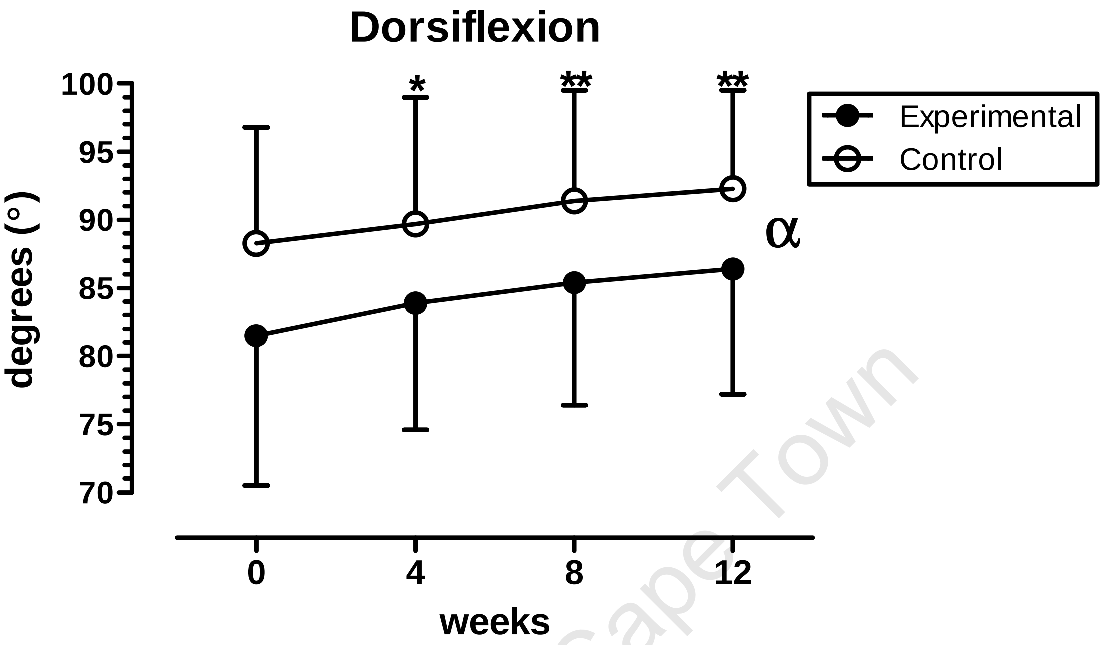
** week 12 versus week 4 (p = 0.0002)

Figure 3.12: *Average hallux plantarflexion ROM of (°) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

3.4.12 Hallux Dorsiflexion Range of Motion

Average hallux dorsiflexion ROM of participants in the experimental and control groups is shown in Figure 3.13. There were no significant differences between groups for left, right and average hallux dorsiflexion ROM, whereas there was a significant difference in the measurement over time for left hallux dorsiflexion ROM ($F_{(3,78)}$ = 19.899; p = 0.00001), right hallux dorsiflexion ROM ($F_{(3,78)}$ = 6.129; p = 0.0009), and average hallux dorsiflexion ROM ($F_{(3,78)}$ = 16.639; p = 0.00001) (Figure 3.13) (Appendix XV). Left hallux dorsiflexion ROM improved significantly at week four (p = 0.0002), week eight (p = 0.0001), and week 12 (p = 0.0001), compared to week zero (Appendix XV). Right hallux dorsiflexion ROM improved significantly at week 12, compared to week zero (p = 0.003); and at week 12 compared to week four (p = 0.002) (Appendix XV).

Average hallux dorsiflexion ROM improved significantly at week four (p = 0.023), week eight (p = 0.0002) and week 12 (p = 0.0001), compared to week zero; and at week 12 compared to week four (p = 0.002) (Figure 3.13).



Significant differences:

α main effect of time (p = 0.00001)

*week 4 versus week 0 (p = 0.023)

**week 8 versus week 0 (p = 0.0002)

**week 12 versus week 0 (p = 0.0001)

**week 12 versus week 4 (p = 0.002)

Figure 3.13: *Average hallux dorsiflexion ROM (°) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

3.4.13 Overall Satisfaction with the Type of Running Shoes, Training and Performance, Lower Limb Function and Comfort and Support

3.4.13.1 Overall Satisfaction with the Type of Running Shoes

The overall satisfaction with the type of running shoes of participants in the experimental and control groups is shown in Table 3.13. There were no significant differences in overall satisfaction with the type of running shoes between groups or over time.

Table 3.13: *Overall satisfaction with the type of running shoes of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	3.7 ± 0.7	4.3 ± 0.6
4	3.8 ± 0.9	4.0 ± 0.7
8	3.9 ± 0.9	4.1 ± 0.5
12	3.6 ± 1.3	4.1 ± 0.6

3.4.13.2 General Satisfaction with Training and Performance

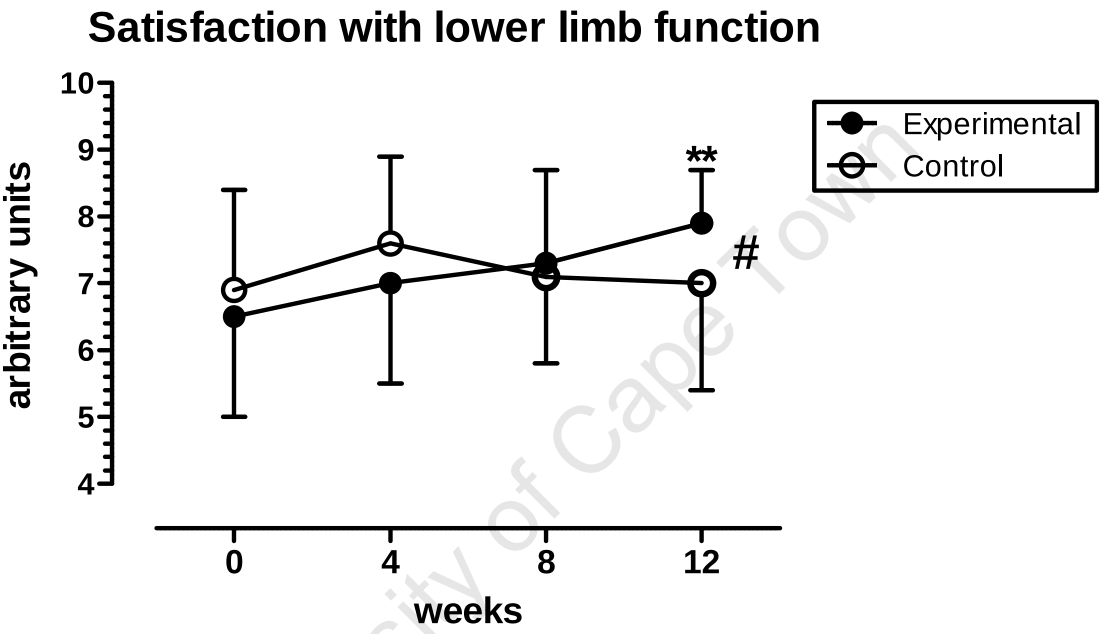
The general satisfaction with training and performance of participants in the experimental and control groups is shown in Table 3.14. There were no significant differences in general satisfaction with training and performance between groups or over time.

Table 3.14: *General satisfaction with training and performance of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	14.6 ± 3.0	13.6 ± 3.4
4	13.6 ± 2.4	13.6 ± 3.5
8	13.8 ± 4.3	13.8 ± 4.0
12	12.8 ± 3.8	13.6 ± 3.8

3.4.13.3 General Satisfaction with Lower Limb Function

The general satisfaction with lower limb function of participants in the experimental and control groups is shown in Figure 3.14. There was a significant interaction between groups over time (F ($_{3,78)}$ = 3.000; p = 0.036) in general satisfaction with lower limb function. General satisfaction with lower limb function improved significantly in the experimental group at week 12, compared to the experimental group at week zero (p = 0.003) (Figure 3.14).



Significant differences:

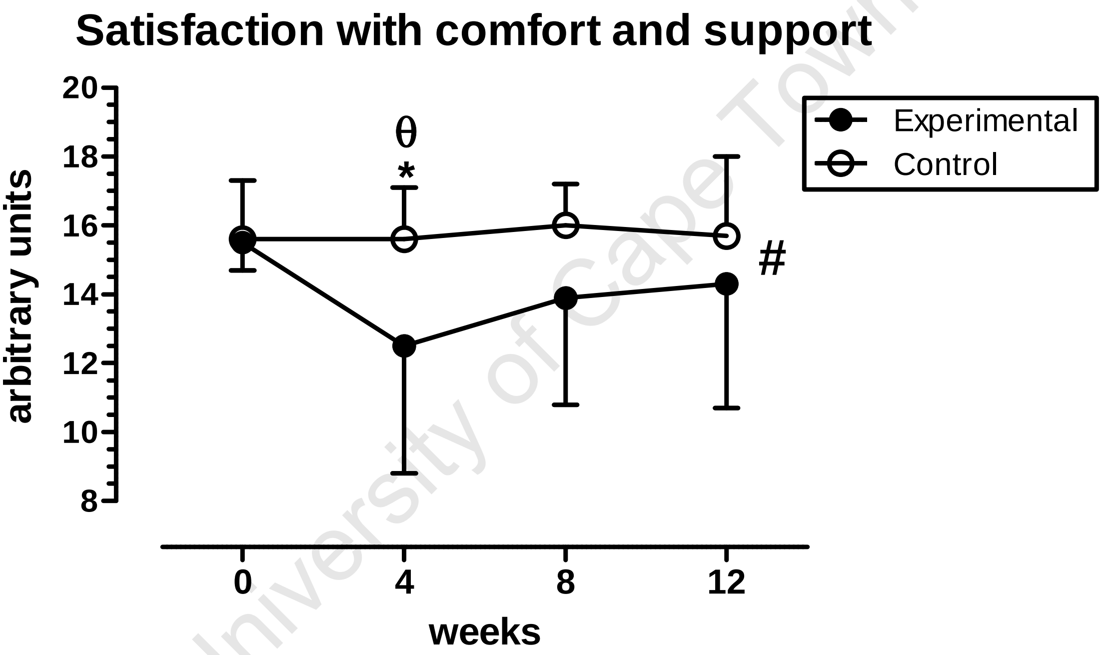
\# interaction of group x time (p = 0.036)

** experimental group week 12 versus experimental group week 0 (p = 0.003)

Figure 3.14: *General satisfaction with lower limb function of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

3.4.13.4 General Satisfaction with Comfort and Support of Shoes

The general satisfaction with comfort and support of shoes of participants in the experimental and control groups is shown in Figure 3.15. There was a significant interaction between groups over time ($F_{(3,78)}$ = 2.653; p = 0.054). There was a significant decrease in general satisfaction with comfort and support of shoes in the experimental group at week four, compared to the experimental group at week zero (p = 0.012). In addition there was a significant decrease in general satisfaction with comfort and support of shoes in the experimental group at week four, compared to the control group at week eight (p = 0.031) (Figure 3.15).



Significant differences:

interaction of group x time (p = 0.054)

* experimental group week 4 versus experimental group week 0 (p = 0.012)

θ experimental group week 4 versus control group week 8 (p = 0.031)

Figure 3.15: *General satisfaction with comfort and support of shoes of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

3.4.13.5 Satisfaction with Continuing to Run in Conventional/Minimalist Shoes

Satisfaction with continuing to run in convention/minimalist shoes scores of participants in the experimental and control groups is shown in Table 3.15. There were no significant differences in satisfaction with continuing to run in conventional/minimalist shoes between groups or over time.

Table 3.15: *Satisfaction with continuing to run in conventional/ minimalist shoes of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	3.5 ± 3.3	3.4 ± 0.5
4	3.5 ± 1.2	3.5 ± 0.7
8	3.7 ± 1.1	3.6 ± 0.5
12	3.7 ± 1.5	3.5 ± 0.7

3.4.13.6 Total Satisfaction Scores

Total satisfaction scores of participants in the experimental and control groups are shown in Table 3.16. There were no significant differences in total satisfaction scores between groups or over time.

Table 3.16: *Total satisfaction scores of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	43.9 ± 3.3	43.7 ± 4.6
4	40.4 ± 8.0	44.4 ± 5.2
8	42.5 ± 7.4	44.6 ± 5.3
12	42.3 ± 8.5	43.9 ± 6.9

3.4.14 Summary of Results

In summary, the main findings of this study were that there was a low overall injury incidence of two (6.9%) for both groups. Only one participant in each group reported a running related injury during the study period. There was a significant difference in the total number of anatomical sites of pain reported by the experimental group at week two compared to the control group. A trend (increase in experimental group from weeks two to week six, compared to the control group) appeared in the weekly incidence of self-reported pain, pain severity scores as well as anatomical sites of pain. However, these were trends only and while these findings might be of practical clinical relevance, they were not statistically significant. In addition, both groups improved in performance over time (left calf endurance, average calf endurance, lower limb muscle power, left hallux plantarflexion ROM, right hallux plantarflexion ROM, average hallux plantarflexion ROM, left hallux dorsiflexion ROM, right hallux dorsiflexion ROM and average hallux dorsiflexion ROM). There was an initial increase in pain and dissatisfaction with the minimalist running shoes between weeks two and six (general satisfaction with comfort and support of the shoes) in the experimental group compared to the control group. Despite some pain and dissatisfaction with the comfort and support of running shoes in the experimental group, the minimalist running shoes did not result in higher injury incidence with a slow progression in running distance. These differences in anatomical sites of pain and dissatisfaction with the minimalist running shoes (general satisfaction with comfort and support of the shoes) in the experimental group resolved at week 12 and the experimental group reported increased general satisfaction with lower limb function. Furthermore, there were no significant differences between groups in the descriptive characteristics. Lastly, there were no significant interactions between groups or over time for weekly training data (weekly running distance and duration of running), rate of perceived exertion scores, weekly incidence of self-reported pain and pain severity scores.

3.5 Discussion

Running footwear is an important extrinsic risk factor as these are often used during endurance running. Running footwear may affect muscle strength, endurance, flexibility, running kinetics, lower limb injury incidence, lower limb pain and performance of an endurance runner[66,151]. There have been studies that have investigated the effects of minimalist running shoes on running related injuries however there have been no studies to date, and to the knowledge of this author, that have investigated the effect of minimalist running shoes on lower limb muscle function, lower limb injury incidence, pain and performance[17,66,84,110,114,119]. Considering the lack of evidence, minimalist running shoes (experimental group) were compared to conventional running shoes (control group) and the effect on lower limb injury incidence, lower limb pain and muscle function was investigated in experienced distance runners. The main finding of this study was the low overall incidence of injury (n = 2) in both groups. Only one participant in each group reported a running related injury during the study period. In addition, there were significant interactions between groups over time for the total number of anatomical sites of pain (per week). Both groups demonstrated significant improvements in calf endurance, lower limb muscle power, hallux plantarflexion and dorsiflexion ROM over time. In addition, general satisfaction with comfort and support of shoes significantly decreased in the experimental group over time. General satisfaction with lower limb function improved significantly in the experimental group over time. This discussion will include the participants, weekly training data, weekly RPE scores, weekly incidence of self-reported pain, lower limb injury incidence, calf endurance, hamstring and calf muscle flexibility, lower limb muscle power, foot posture index, hallux plantarflexion and dorsiflexion ROM as well as the satisfaction questionnaire scores.

3.5.1 Participants

3.5.1.1 Sample Size

Recent studies that investigated the effects of different footwear on lower limb injury incidence, running related injuries, running kinematics, kinetics and neuromuscular functions had sample sizes of between five and 94 participants[20,21,36,115,119,122,126]. Four of these studies comprised of recreational and competitive endurance participants[21,36,122,126]. One study included female runners[115] and one study included both male and female participants[20]. Furthermore, a variety of different categories of runners and genders of runners (recreational, competitive, male and female) have been used in these studies, which limits the potential for accurate and objective comparison between studies. It is thus difficult to deduce whether the beneficial results obtained in these studies could be applicable to male experienced distance runners. Therefore participants included in this study were experienced male distance runners only.

The results of this study also showed trends for increased weekly self-reported pain and pain severity scores between weeks two and six in the experimental group, compared to the control group. The lack of significant differences between groups in these variables unfortunately suggests that this study may have been underpowered for these outcome measures. This is largely due to the low injury incidence in this sample; and the potential over-estimation of injury incidence that was used to calculate the sample size for this study. An anticipated injury incidence of between 50% to 60% in the experimental group, and an anticipated injury incidence of 5% in the control group were used to calculate sample size. However, it is recognised that a larger sample size may have been required to compensate for the relatively short study period of 12 weeks, and the low injury incidence in this study.

3.5.1.2 Descriptive Characteristics

There were no significant differences between groups in age, mass, stature, BMI, sum of seven skinfolds, body fat percentage and lean body mass (Table 3.4, page 76). The participants that took part in research by Schultz et al[122] were an average age of 30 ± 5 years, height of 172.0 ± 0.4 cm and body mass of 70 ± 7 kg. These results are similar to the findings of this study. Furthermore, there were no significant differences between groups in training characteristics including: years of running experience; weekly training distance; best time for 10 km race and best time for 21.1 km race (Table 3.5, page 77). In addition, there was a similar representation of sports that the participants took part in during the study period in both groups (Table 3.6, page78). This mitigated any potential confounding effects between groups. Braustein et al[21] reported that the participants in their study completed three to four sessions of running per week. This is similar to the findings of this study. However, no additional sports to running were recorded in Braustein et al[21]; therefore differing from this study.

3.5.2 Weekly Training Data, Weekly Rate of Perceived Exertion Scores, Weekly Incidence of Self-Reported Pain, Pain Severity Scores and Anatomical Sites of Pain

3.5.2.1 Weekly Running Distance and Duration of Running

The study showed no significant differences in weekly running distance and duration of running between groups or over time (Table 3.7, page 79). Therefore, both the experimental and control groups covered similar weekly running distances from week zero to week 12.

During the four week training programme, the experimental groups' weekly running distance was slightly less compared to the control group however, this decrease was not significant. As a result, both the experimental and control groups' musculoskeletal systems were exposed to similar stresses with regards to weekly running distance (mileage) and duration. Buist et al[23] and Bredeweg et al[22] incorporated similar running distances and duration of running for the participants that took part in these two studies. As a result, similarities can be seen between these two studies and this study with regards to controlling and closely matching weekly running distance and duration of running between two groups. This ultimately decreased the potential of these extrinsic risk factors namely running distance and duration of running, to affect the results of the study as these factors were similar in both groups. Yeung and Yeung[149] suggested that runners who trained for more than 30 minutes a day were at an increased risk of injury, compared to runners who trained for 15 to 30 minutes a day. However, this study involved experienced male endurance runners who ran, on average, more than 30 minutes a day. It is therefore recommended that future research examines the effects of minimalist running shoes on the impact of training for more than 30 minutes a day in experienced distance runners.

3.5.2.2 Rate of Perceived Exertion Scores

The study showed no significant differences in RPE scores between groups or over time (Table 3.8, page 80). Hreljac and Ferber[66] observed that increased running speeds produced greater forces on the related musculoskeletal structures. This would increase RPE scores[48,80]. Al-Rahamneh and Eston[2] found a strong linear relationship between RPE and submaximal oxygen consumption during a graded exercise test and the ramp exercise test. Therefore it may be assumed that as exercise intensity increases, so does the RPE. LaCaille et al[79] supported these findings. An increase in training intensity resulted in a shift to the left of the stress-frequency curve, which suggests that fewer repetitions will be required for structures to enter an '*injury zone*'[66]. In this study, RPE scores were relatively low. This explains the possibility that the participants' musculoskeletal systems did not shift into the '*injury zone'* as a result of training intensity. In addition, as the participants were endurance runners (low training intensity), the RPE scores were relatively low.

3.5.2.3 Weekly Incidence of Self-Reported Pain

This study showed no significant differences in weekly incidence of self-reported pain between groups or over time (Figure 3.5, page 81). A plausible explanation for this may be that both groups experienced pain during running due to the normal stresses that are placed on the musculoskeletal system. Running ground forces range between two and three body weights.

It has been suggested that muscle forces contribute an additional three body weight of force during slow jogging around the hip joint and muscles that cross the ankle joint contribute an additional seven body weight of force during running[42]. An alternative explanation for the absence of differences in pain between groups may have been the four week training programme that aimed to slowly condition and introduce the minimalist running shoes and stresses related to these shoes[132]. The biomechanical load was low and slightly increased throughout the training programme. In addition, the programme aimed to load the musculoskeletal system in a sport-specific way[22,132]. The inclusion of the four week training programme appeared to be successful in allowing for the participants' bodies and musculoskeletal systems, in the experimental group, to positively adapt to the minimalist running shoes.

However, weekly incidence of self-reported pain appears to be higher in the experimental group compared to the control group from week one through to week eight (Figure 3.5, page 81). Thereafter the weekly incidence of self-reported presence of pain in the experimental group decreased to below the control groups' percentages. A trend (increase in experimental group from weeks two to week six, compared to the control group) appeared in the weekly incidence of self-reported pain, pain severity scores as well as anatomical sites of pain. This trend (increase in experimental group from weeks two to week six, compared to the control group) may represent the musculoskeletal and biomechanical adaptations that potentially occur when transitioning from conventional into minimalist running shoes. Changes in ground contact forces and potential alterations in leg stiffness, as a result of the minimalist running shoes, may have resulted in these musculoskeletal and biomechanical adaptations[16]. These musculoskeletal and biomechanical changes that occurred aimed to minimise forces. Future research should investigate this further as this finding is important for clinical significance. Furthermore, the conventional group may have reported similar self-reported pain scores compared to the experimental group as endurance running is not solely associated with pain. Fatigue due to high training volumes and potential EIMD is also associated with endurance running[89]. These factors may have been reflected in both groups' pain scores. Unfortunately, these data highlight that the study may have been underpowered for these outcome measures, largely due to the low incidence of injury in this sample, and the potential over-estimation of injury incidence when sample size was calculated. No other studies have investigated weekly incidence of self-reported pain in experienced endurance runners while transitioning from conventional into minimalist running shoes; therefore it is not possible to compare the findings of this study to previous research. Future research should investigate the effect of transitioning from conventional into minimalist running shoes on weekly incidence of self-reported pain scores.

3.5.2.4 Pain Severity Scores

This study showed no significant differences in pain severity scores between groups or over time (Table 3.9, page 82). Pain severity scores may be linked to weekly incidence of self-reported pain[125]. As a result, the same argument presented in weekly incidence of self-reported pain (Section 3.5.2.3, page 99) explains the findings and results of the pain severity scores. In addition, the trend (increase in experimental group from weeks two to week six, compared to the control group) can be seen in the pain severity scores. This trend may represent the musculoskeletal and biomechanical adaptations that potentially occurred when transitioning from conventional into minimalist running shoes. Low pain severity scores were reported in both groups therefore demonstrating the normal stresses that are placed on the musculoskeletal system as a result of low intensity endurance running[66]. In addition, the repeated bout effect of EIMD may have caused participants to become accustomed to repetitive loading and changes in loading patterns over time[5,29,65,97], therefore resulting in a gradual reduction in pain severity scores.

Unfortunately, there were no studies which investigated pain severity scores in endurance runners while transitioning from conventional into minimalist running shoes; therefore it is not possible to compare the findings of this study to previous research. In addition, the measurement of *'pain'* may not be appropriate for a study like this. The reason for this is that pain may be associated with injury which may further explain the low pain severity scores that were reported in both groups due to the low injury incidence. The instruments that were used to assess pain severity may not have been accurate in reflecting true pain scores as pain is often influenced by many factors. In future research, perhaps the word *'discomfort'* should be used instead of *'pain'*. Furthermore, future research in this field could utilise the visual analogue scale to measure footwear and musculoskeletal discomfort during running[90]. An adapted version of the Nordic musculoskeletal questionnaire could also be used[35].

3.5.2.5 Anatomical Sites of Pain

This study showed a significant interaction between groups over time for total number of anatomical sites of pain per week (Figure 3.6, page 83). The experimental group reported a steady increase in anatomical sites of pain from week zero to week four, followed by a decrease from week four to week five. This could be due to the change from conventional running shoes into minimalist running shoes. The minimalist running shoes generated a mid-foot strike or fore-foot strike followed by lowering of the heel, mimicking a normal barefoot running gait pattern[82]. It may therefore be hypothesised that a greater amount of contraction force (concentric and eccentric contraction) and control was required from the lower limb muscles due to this rapid change in running shoes, gait and running style.

Thus anatomical sites of pain reported increased among the experimental group compared to the control group. This further reflects the musculoskeletal and biomechanical adaptations that potentially occurred during the transition period from minimalist into conventional running shoes. This may have been due to the changes in ground contact forces, potential alterations in leg stiffness (from the minimalist running shoes) as well as the repeated bout effect of EIMD[5,16,29,65,97]. The control group reported minor changes in the number of total anatomical sites of pain for the 12 week study period. A possible explanation for this may be that the control group continued to run in conventional running shoes therefore no change in lower limb contraction force, control, running shoes, gait and running style occurred throughout the 12 week study period. It has been hypothesised that the lower limb muscles in the control group were working equally whereas the experimental groups' calf and anterior shin muscles worked harder to adapt to the new running style and gait pattern as a result of the minimalist running shoes.

Another possible explanation for the different total number of anatomical sites of pain reported between groups is that the minimalist running shoe caused different recruitment of muscles and therefore this may be associated with EIMD and DOMS due to unaccustomed loading of muscles during running (compared to running in conventional shoes). Thus the runners in the experimental group may have been experiencing DOMS which may further explain the significant difference in the number of total anatomical sites of pain between groups. It has been noted previously that there were no significant differences in general sports activities between groups (Table 3.6, page 78). However, these additional sports may have affected anatomical sites of pain depending on the intensity of the exercise. In future studies, it is recommended that participants should not be allowed to take part in any other sports except running, during the study period. This could help eliminate any anatomical sites of pain reported that have originated from participation in sports and activities other than running.

In addition, this study also found that, in the experimental group, the left posterior calf was the pain area reported most frequently. This was followed by the right posterior calf, the left medial calf and left lateral calf (Figure 3.7 and 3.8, page 84). This further substantiates the proposed increased contraction force (concentric and eccentric) that occurred in the calf muscles and anterior shin muscles in the experimental group, due to the change from conventional to minimalist running shoes. This novel finding may reflect the initial musculoskeletal and biomechanical adaptations that potentially occur when transitioning from conventional into minimalist running shoes. In the control group, the left posterior thigh, left posterior calf and the right medial thigh were the anatomical sites of pain reported most frequently. This was followed by the right posterior thigh, right posterior calf and left medial thigh. Subsequently, the right and left medial calf were reported (Figure 3.7 and 3.8, page 84).

There was no specific pattern to the number of total anatomical sites of pain reported in the control group. This could be due to normal stresses placed upon the lower limb muscles while running in conventional running shoes.

Numerous studies have established that endurance running is associated with the risk of musculoskeletal pain and running related injuries[23,34,39,49,103,108,119,128]. Chang et al[27] observed that 44% of surveyed participants reported lower limb pain that was related to running. Chang et al[27] found that the most common running related injury and associated pain area was knee pain (33%). This was followed by foot/ankle pain (25%), thigh pain (17%), shin pain (16%), lower back pain (5%) and hip pain (5%). In addition, Rauh et al[105] found that the most common site of pain and injury was the shin (42%) in female runners and the knee (30%) in male runners. The results of this study differ from those demonstrated by Chang et al[27] and Rauh et al[105]. The difference in findings may be attributed to the fact that, in this study, the participants ran in minimalist and conventional running shoes whereas Chang et al[27] and Rauh et al[105] did not include minimalist running shoes. As a result, it is proposed that the calf and anterior shin muscles were not under as much stress and required eccentric contraction compared to the experimental group[82,114]. In addition, the differences found in the number of total anatomical sites of pain between this study and other studies may be attributed to the various definitions used for a running related injury and anatomical sites of pain, the vast differences in the number of participants, the different genders as well as the various race distances investigated[23,27,34,39,49,103,105,108,119,128].

3.5.3 Injury Incidence

One participant in the experimental group and one participant in the control group sustained running related injuries respectively. As only one participant in the experimental group sustained a running related injury, the hypotheses regarding any potential mechanisms or contributing factors related to the development of injuries should be interpreted with caution. The participant in the experimental group sustained a running related injury in week four (Figure 3.9, page 85). A possible explanation for this injury may be that the minimalist running shoes placed stress upon the lower limb muscles, specifically the calf and anterior shin muscles, even though the participant was following the four week training programme. Rothschild[114] stated that barefoot and minimalist running resulted in higher preactivation of the gastrocnemius and soleus muscles thus increasing the stress in these muscles. In addition, due to increased proprioceptive feedback during minimalist running, muscle contractions in the intrinsic foot musculature result in internal active support, therefore increasing the stress on these muscles[114].

In this study, due to the increase in stress upon the gastrocnemius, soleus, anterior shin muscles and the intrinsic foot musculature, theses muscles were unable to continue supporting the forces placed upon them. Thus a shift into the '*injury zone'* occurred[66]. Rixe et al [110] reported that a minimalist running shoe/style had been suggested to minimise running related injuries.

In addition, many studies have proposed that the use of barefoot and minimalist running has many advantages including: improved sensory feedback; proprioception; and reduced impact forces due to the fore-foot and mid-foot strike that occurs[51,110,114]. However, one participant in the experimental group did get injured in this study. Another explanation for this could be that the participant required an extended and individualised training programme to assist with a longer and smoother transition into the minimalist running shoes. This highlights the fact that each runner is individual and should follow an individual training programme according to that runner's specific needs and weaknesses. However, no evidence exists for a reduction in lower limb injuries, pain and improved performance associated with the use of minimalist shoes. Therefore, more research is needed in the areas of lower limb injury incidence, pain and performance in runners using minimalist shoes[114].

There was one participant in the control group that sustained a running related injury in week 12. This participant reported pain in the left lateral calf (Figure 3.9, page 85). A probable explanation for this injury could have been a result of a change in terrain from flat runs into a hilly run. Incorrect training surfaces and terrain can result in altered biomechanics therefore increasing the risk of running related injuries[50]. In addition, Telhan et al[131] examined lower limb joint kinetics during moderately sloped running and observed changes in knee power absorption and hip power. This could lead to running related injuries. Both injuries in the experimental and control groups involved the participants' muscles (calf and peronei muscle strains). Rochcongar et al[111] observed that the most common injuries in 1153 runners were tendonitis (66%), joint lesions of the knee and ankle (58%), and muscle injuries (47%). Taunton et al[129] and Schwellnus and Stubbs[119] reported that PFPS was the most common and frequently reported injury. The results of this study differ to Rochongar et al[111], Taunton et al[129] and Schwellnus and Stubbs[119]. A plausible explanation for this may be that previous studies did not include runners using minimalist running shoes (following a four week training programme). Therefore, the endurance runners in this study were exposed to different stresses in the lower limbs as a result of running in minimalist running shoes thus injury incidence and classification differed.

Taunton et al[128] established a 30% injury rate. This differs to the low injury incidence that was found in this study. It was also noted that the annual incidence rate of running injuries may be as high as 90% in runners training for a marathon[49]. This point could further explain the low injury incidence in this study as the participants were not training for a marathon.

Another possible reason for the low injury incidence could be due to the difference in study design as well as a relatively small sample size that was used in this study as previous research has included larger sample sizes (n = 177[119], n = 53[39], n = 647[135], n = 9380[34] and n = 88[103]). Fredericson and Misra[49] found that running more than 64 km per week increased the relative risk for injury to three. This could further explain the low injury incidence in this study as the participants did not run more than 60 km per week. Lastly, as the experimental group followed the four week training programme, musculoskeletal and biomechanical adaptations occurred under a controlled situation. This could therefore explain the low injury incidence in this study.

3.5.4 Calf Endurance

The study showed no significant differences in calf endurance between groups however, there was a significant difference over time in average calf endurance (Figure 3.10, page 86). There were also significant differences in left calf endurance over time (Appendix XV). There were no significant differences in right calf endurance between groups or over time. Lower limb dominance was not assessed in this study as running in theory is a bilateral sport. Therefore a plausible explanation for this difference in right and left calf endurance may have been related to leg dominance as well as participation in other sports[25,81,81]. In addition, due to the fact that the calf raise test was used as a repeated measure, a cumulative effect from week to week may have occurred, thus leading to a significant increase in left and average calf endurance. As the calf raise test was used as a repeated measure, the test itself may have resulted in the increase of left and average calf endurance over time. Another factor to consider is the four week training programme. This programme included hopping sessions (calf muscle training) per day, in both the experimental and control groups. As hopping mainly involves the calf muscles, this daily exercise could have influenced the endurance and strength of these muscles in both groups, therefore supporting the finding that no significant differences occurred between groups. Future studies should include a control group that does not participate in any calf muscle training. This may help elucidate whether changes in calf muscle endurance occur in response to training in minimalist running shoes. In addition, an increased study period in future studies should be considered.

Madeley et al[85] compared the endurance of the ankle plantarflexor muscles in two groups (one with medial tibial stress syndrome and one without). The group without medial tibial stress syndrome performed a mean of 33 ± 8.6 calf raises. In this study the experimental group performed 28.9 ± 8.0 calf raises at week 12 and the control group 27.0 ± 3.9 calf raises at week 12 therefore differing slightly with previous research. This difference could be attributed to the difference in descriptive characteristics (gender, age, recreational versus competitive runners and endurance versus sprint runners) in previous research compared to this study[85].

Therefore, the findings of this study indicate that the minimalist running shoes did not lead to improved calf endurance in the experimental group. According to the knowledge of the author, no studies have investigated the effects of minimalist running shoes on calf endurance. The majority of studies have focused on investigating the effects of running shoes on running kinematics, kinetics and running related injuries[20,21,30,36,51,66,84,109,110,114,115,119,122,126]. Future research should investigate whether endurance runners using minimalist running shoes have greater calf endurance compared to other sporting disciplines. In addition, it is recommended that future research should examine the effect of minimalist running shoes on calf endurance in experienced distance runners.

3.5.5 Hamstring Muscle Flexibility

The study showed no significant differences in hamstring muscle flexibility between groups or over time (Table 3.10, page 87). A reasonable explanation for this finding may be that both the conventional and minimalist running shoes did not have a direct effect on hamstring muscle flexibility. In theory, each individual runner runs with a different running style. This may therefore influence muscle flexibility. In a review article, Bonacci et al[17] stated that performance was influenced by running footwear and may therefore alter running patterns, muscle activity as well as neuromuscular factors. In addition, each runner will demonstrate different neuromuscular changes (including muscle flexibility) when orthotics and footwear are used. Furthermore, the participants in this study were experienced endurance runners. This could influence hamstring muscle flexibility when compared to other sporting disciplines. During prolonged periods of running, the hamstring muscles are constantly in a relatively shortened position. As a result, a longer time period may be required to determine changes in hamstring muscle flexibility in endurance runners. Thus the findings of this study (no significant changes in hamstring flexibility) could be due to the short study period. Furthermore, minimalist running shoes offer less cushioning. Nigg and Liu[95] found that vertical impact force peaks during running when changing the midsole hardness of running shoes. This is associated with changes in muscle activation levels in the lower extremity. Another credible explanation may be that initially, muscle compliance of the hamstrings may increase to help assist with the increased vertical impact force due to the decreased cushioning offered from the minimalist running shoes. Therefore no significant changes in hamstring flexibility were recorded. Future research should examine the long-term effects of minimalist running shoes on hamstring muscle flexibility.

3.5.6 Calf Muscle Flexibility

The study showed no significant differences in calf muscle flexibility between groups or over time (Table 3.11, page 87). A probable explanation for this finding may be that as the participants in both groups reported increased anatomical sites of pain predominantly in the calf muscles (Figure 3.7 and 3.8, page 84), the muscle flexibility of the calf was affected. Pain and DOMS are often a clinical symptom of EIMD that alters muscle flexibility[1]. Due to the increased eccentric muscle contractions in the lower limb musculature, EIMD may have resulted in the onset of DOMS that in turn alters the passive stiffness of the muscles and results in decreased flexibility[5,29,53,65,97]. Active and passive tension increases as a result of endurance running training and EIMD therefore resulting in decreased muscle flexibility[14,24,61,62,117,142]. These increased eccentric muscle contractions may have been an outcome as a result of the hopping sessions (calf muscle training) that were part of the four week training programme (both groups), as well as a change in running shoes (experimental group). In addition, initial tendon compliance during endurance exercise may increase tension in the muscle belly thus decreasing calf flexibility. Therefore a longer study time period may determine changes in calf muscle flexibility once the calf muscles have adapted to the change in forces resulting from minimalist running shoes. Future research should examine the long-term effects of minimalist running shoes on calf muscle flexibility.

3.5.7 Lower Limb Muscle Power

The study showed significant differences in lower limb muscle power over time (Figure 3.11, page 88). A possible reason for the increase in vertical jump height in both groups could be due to the learning effect. The learning effect was a potential limitation in this study. Unfortunately, there are no other studies that have investigated the effect of minimalist running shoes on lower limb muscle power. Previous research has stated that fatigue and DOMS may result from EIMD which could further decrease muscle power[37,75,87]. However, the findings of this study do not support this theory. In the first four weeks of the study period when the participants were exposed to increased forces on the musculoskeletal system (due to the additional hopping sessions and minimalist running shoes) possible fatigue and DOMS may have occurred. Therefore a decrease in muscle power from week zero to week four would have been expected. However this did not occur. This could be due to the beneficial effects of the four week training programme and hopping training (calf muscle training). Future studies should include a control group that does not participate in any calf muscle training. In addition, it has been proposed in the literature that running in minimalist running shoes may increase lower limb muscle power[82,110,114]. The findings of this study do not support this theory as there were no significant differences in lower limb muscle power between groups. This could be due to the limited time period of the study. It is not known if the reported changes in lower limb muscle power would have persisted if the participants continued training after the 12 week study period.

Therefore minimalist running shoes do not improve short-term lower limb muscle power. It is recommended that future research should investigate the long-term effects of minimalist running shoes on lower limb muscle power.

3.5.8 Foot Posture Index

The study showed no significant differences in foot posture index between groups or over time (Table 3.12, page 89). A reasonable explanation for this finding may be that the study period was not long enough to determine changes in foot posture index between groups or over time. It has been postulated that minimalist running shoes should improve foot posture index as the decrease in cushioning of these shoes increases proprioceptive feedback during minimalist running. Therefore an escalation in the activation of the intrinsic muscles of the foot occurs. This increases the internal active support of the foot. This in turn strengthens the arches of the foot and therefore over pronation is restricted and foot posture index improves[110,114]. However the findings of this study do not support this theory as both groups demonstrated pronation scores in the foot posture index throughout the 12 week study period. This could be due to the fact that conventional running shoes do not promote intrinsic foot muscle strengthening due to the additional support offered from these shoes. Intrinsic foot muscle strengthening may take time when running in minimalist running shoes[110]. This could explain why foot posture index scores were pronated in both groups. The intrinsic muscles of the participants' feet were not yet adequately developed during the 12 week study period, thus the medial longitudinal arches of their feet were collapsing. This potential weakness of intrinsic foot musculature may offer a cause for concern when transitioning from conventional into minimalist running shoes as this may increase the risk of sustaining a running related injury. Therefore, it is vital to follow a gradual training programme to assist with slowly strengthening the lower limb (and foot) muscles during the transition period. It is recommended that future research should include lower limb (and foot) muscle exercises (in addition to calf muscle training) as part of the training programme.

3.5.9 Range of Motion of Hallux Plantarflexion and Dorsiflexion

The study showed significant differences in left, right and average hallux plantarflexion and dorsiflexion ROM over time (Figure 3.12, page 90 and Figure 3.13, page 91). There were no significant differences in left, right and average hallux plantarflexion and dorsiflexion ROM between groups. Hallux ROM has been predicted to increase when running in minimalist running shoes as the runner adopts a fore-foot or mid-foot strike gait pattern[82,98]. During the gait cycle pressure begins on the lateral border of the heel and moves rapidly to the medial aspect of the heel and the fore-foot[98]. Most of the pressure is then concentrated under the first and second metatarsal heads[98].

Therefore running in minimalist shoes may increase hallux ROM due to the decreased support offered from the shoes and the change in pressure application to the different anatomical structures of the foot[98]. In addition, balance improves as well as an increase in strength of the intrinsic foot muscles therefore influencing the hallux ROM. This change could possibly decrease running related injuries.

Previous research has established that conventional running shoes also increase hallux dorsiflexion ROM which further increases the mechanical stress on this joint[122]. Therefore, future research is needed to clarify whether an increase in hallux dorsiflexion is beneficial or not. However, the increase in hallux plantarflexion and dorsiflexion ROM in this study was not a result of the minimalist running shoes as the increase occurred in both groups. A likely explanation for this finding may be that, despite the fact that intra-rater reliability was tested in the reliability study; the goniometer reading for both of these ROM measurements may have been inaccurate as a normal goniometer was used instead of a digital toe goniometer. It is difficult to measure ROM in this joint therefore inaccurate measurements may have influenced the results. This is known as measurement error. Future research involving this joint should be measured with a digital toe goniometer. In addition, the continuing increase in hallux dorsiflexion and plantarflexion ROM may be attributed to a potential learning effect, with participants becoming more familiar with this test at each data collection session. This is despite all participants being required to complete a familiarisation session prior to testing. In addition, changes in hallux dorsiflexion and plantarflexion ROM occur over time[88]. It is therefore not possible to speculate about potentially clinically relevant changes that may have occurred after the 12 week study period. Further studies are required to determine whether long-term changes in hallux dorsiflexion and plantarflexion ROM occur with running in both minimalist and conventional running shoes. Hallux plantarflexion and dorsiflexion ROM has been measured before[88], however unfortunately, no studies have measured hallux plantarflexion and dorsiflexion ROM in runners running in minimalist shoes. Thus future research should investigate the effects of hallux plantarflexion and dorsiflexion ROM on intrinsic foot muscle strength and balance in runners.

3.5.10 Satisfaction with the Type of Running Shoes and Performance

The study showed no significant differences in overall satisfaction, general satisfaction with training and performance and satisfaction with continuing to run in conventional/minimalist shoes scores between groups or over time (Table 3.13, page 92, Table 3.14, page 92, Table 3.15, page 95). Both groups appeared to be equally satisfied with all aspects relating to these specific sections of the satisfaction questionnaire. In addition, the control group have not run in minimalist running shoes before thus they do not know how it feels to run in these types of shoes. Therefore both the experimental and control groups were equally satisfied with continuing to run in conventional/ minimalist shoes.

These findings also show that both the minimalist and conventional running shoes did not hamper or improve satisfaction with training and performance, according to the participants' satisfaction scores.

The study showed significant differences in general satisfaction with comfort and support of shoes, between groups over time (Figure 3.15, page 94). The general satisfaction with comfort and support of shoes decreased significantly in the experimental group at week four's data collection session. A potential explanation for this is that the experimental group had changed from conventional into minimalist running shoes, offering less support due to the design of the shoe[82]. As a result, the experimental group was not use to this decreased support therefore lowering their satisfaction scores. In addition, the musculoskeletal and biomechanical adaptations were taking place during these first weeks therefore decreasing the general satisfaction with comfort and support of the minimalist running shoes. Thereafter, the general satisfaction with comfort and support of the shoes increased in the experimental group. This could be due to the musculoskeletal adaptation period plateauing. The control group's general satisfaction with comfort and support of running shoes remained consistent during the study period. These types of shoes are designed to offer more support while running[82], therefore explaining the reason for these findings. A lengthy time period is required for a runner to adapt to the changes from transitioning from conventional into minimalist running shoes[114], including comfort and support; therefore a longer study period may have shown an improvement in the experimental group over time.

Furthermore, the study showed significant differences in general satisfaction with lower limb function between groups over time (Figure 3.14, Page 93). The experimental group's general satisfaction with lower limb function increased at each data collection session. A potential for the placebo effect in the experimental group may have influenced these findings. Receiving a new pair of minimalist running shoes may explain why only the experimental group's general satisfaction with lower limb function increased from week to week. This group may have shown this increase in satisfaction due to the impression that minimalist running shoes should increase muscle performance and strength of the lower limbs. This stems from general advertising. Another reasonable explanation for this significant difference between groups may be that popular media and advertising are highlighting minimalist running shoes and the potential gains in performance and lower limb muscle strength. This may impact greatly on perceived satisfaction and result in recall bias. In addition, the lack of blinding of groups regarding the shoes may have influenced these scores. Lastly, the beneficial effects of the musculoskeletal and biomechanical adaptations at week 12 may have resulted in the increase in general satisfaction with lower limb function in the experimental group. To date, various studies have utilised the satisfaction questionnaire to measure satisfaction levels[59] however, no previous studies have investigated the influence of minimalist running shoes on satisfaction levels. Future research should examine the long-term effects of running in minimalist shoes on satisfaction levels.

3.5.11 Study Limitations and Recommendations for Future Research

There were several limitations linked to the design of this study. The main potential limitation of this study was that the sample size was too small. The lack of significant differences between groups in weekly self-reported pain and pain severity scores unfortunately suggests that this study may have been underpowered for these outcome measures. This is largely due to the low injury incidence in this sample; and the potential over-estimation of injury incidence that was used to calculate the sample size for this study. However, it is recognised that a larger sample size may have been required to compensate for the relatively short study period of 12 weeks, and the low injury incidence in this study. Therefore, more participants were needed to improve power in this study.

Another potential limitation of this study was participant compliance with regards to all aspects other than the four week training programme. The online training log was used to control compliance of training sessions per week during the unsupervised four week training programme, as well as for the remainder of the study period. Similarly, Buist et al[23] and Bredeweg et al[22] utilised a training log to control participant compliance in the preconditioning programme that was implemented in their study. However, some of the participants did not complete the online training log at the end of each week. At times, some participants only completed the online training log well into the following week. This therefore introduced recall bias. Furthermore, the possibility exists that participants could have failed to perform their respective running training sessions per week (40-60 km per week), yet stated otherwise. It has also been recognised that the hopping programme may have introduced some confounding of the results due to the calf muscle training effect associated with the hopping sessions. Therefore future studies should include a true control group that does not participate in calf muscle training. In addition, single blinding was attempted in this study but logistically was not possible to maintain. The reason for this was that some participants needed to inform the investigator of which group they were in due to questions that were asked, anatomical sites of pain that were experienced and injuries that occurred.

An additional limitation of this study was the potential for contamination amongst the sample. Participants in both groups trained in running clubs during the study period. This may have increased the participants’ awareness of the differences in the four week training programme between the two groups. Participants may have believed that their respective running shoes were superior to the alternative groups’ running shoes. This perception may have influenced the subjective ratings of general satisfaction scores. A further limitation of this study is that the training programme consisted of only four weeks. A follow up was conducted at four weeks after completion of the respective four week training programme. There appears to be several benefits associated with a gradual transition training programme that is followed over an optimal duration of time.

In some ways, this study may be seen as a pilot study of a transitional training programme. This may be due to the fact that the training programme consisted of only four weeks as well as the small sample size used in this study. To date, current literature recommends that the transition period from conventional into minimalist running shoes should ideally consist of between four to eight weeks[110,114] however, future research in this field is required.

Due to different running styles, some runners may require a longer period to transition from conventional into minimalist running shoes. However, the long-term effects of the results obtained in this study and current literature are unknown. Therefore it is recommended that future research examining the effects of minimalist and conventional running shoes on lower limb injury incidence, pain and muscle function in experienced distance runners should continue for at least six months. In addition, a further limitation was that the participants took part in the study while continuing with their additional sports and training routines above running (Table 3.6, page 78). These additional sporting activities may have presented a potential risk of influencing pain and performance levels throughout the study period. Thus, it is suggested that future studies investigating the effects of minimalist and conventional running shoes on lower limb injury incidence, pain and muscle function in experienced distance runners should exclude additional sporting activities.

Financial constraints meant that only the experimental groups' running shoes were sponsored. The study was unable to sponsor the control groups' running shoes and as a result, the control group participants ran in different conventional shoe brand names. This could have affected the findings in this study hence; it is recommended that future research should include the same brand name of running shoes in both groups. The potential for poor reliability of goniometric measurements of the hallux plantarflexion and dorsiflexion ROM is another limiting factor in this study. Future research should utilise a digital toe goniometer for increased accuracy. Furthermore, the natural competiveness of male participants as well as the learning effect may have influenced the results of the study. It is recommended that future research involving the vertical jump test, should remove all chalk marks from the wall after each participant has jumped to help diminish the competition effect. A vertical jump tester may also be used.

3.6 Summary

In summary, the results of this study suggest that the use of minimalist or conventional running shoes does not increase the incidence of running related injuries in the lower limbs[84,110,114]. There was a low overall lower limb injury incidence in both groups. In addition, no changes in lower limb muscle function occurred when running in conventional or minimalist shoes over a period of 12 weeks. Lower limb pain (significant differences between groups in anatomical sites of pain) increased during the initial transition period when changing from conventional into minimalist running shoes potentially due to the musculoskeletal and biomechanical adaptations. The running training programme used in this study was a slow transition while using minimalist shoes. This was accompanied by a hopping programme (calf muscle training) that was performed by both groups. A trend (increase in experimental group from weeks two to week six, compared to the control group) appeared in the weekly incidence of self-reported pain, pain severity scores as well as anatomical sites of pain. This trend may represent the musculoskeletal and biomechanical adaptations that potentially occurred when transitioning from conventional into minimalist running shoes. Thereafter, once these adaptations reached a plateau, lower limb pain decreased and satisfaction appeared to increase. In addition, runners should transition from conventional into minimalist running shoes with a training programme[110,114] to help prevent running related injuries and lower limb pain from occurring. Clinically, this study highlights the benefits of including a transition training programme with minimalist running shoes upon purchase to assist with a comfortable and successful transition to help decrease the risk of sustaining a running related injury. Furthermore, clinicians should utilise these findings when recommending running shoes to patients as well as when treating running related injuries. The musculoskeletal and biomechanical adaptation period should form part of patient education. It is recommended that future studies should evaluate the long-term effects of minimalist running shoes on lower limb injury incidence, pain and muscle function in experienced endurance runners.

CHAPTER 4: SUMMARY AND CONCLUSION

Recreational and competitive distance running is a popular form of exercise. The health benefits are substantial, therefore health professionals frequently prescribe running to promote physical activity[22,49,66,118,119]. Despite these beneficial effects, runners experience frequent musculoskeletal injuries[73]. The incidence of running related injuries is high. Epidemiologic evidence indicates that the annual risk of developing a running related injury varies from 37% to 56%[75,119]. These injuries are often located in the lower extremities. The knee and lower leg are mostly affected[22,66]. Running shoes are an important extrinsic risk factor that may be associated with the development of running related injuries[22]. Minimalist running shoes are gaining popularity, and there is anecdotal evidence to suggest that use of these shoes is increasing amongst runners. Minimalist running shoes are currently the newest design and are considered to be less rigid compared to conventional running shoes. It is postulated that minimalist running shoes offer less support for the foot and lower extremity therefore stimulating and strengthening the muscles that control dynamic and static stability[20]. This should ultimately minimise running related injury risks and enhance muscle performance[84,110,114]. However there is little or no evidence to support the hypothesis that running in minimalist shoes may be associated with a potential decreased risk of running related lower limb injuries and pain; and improved lower limb function, compared to running in conventional shoes. Therefore, the overall aim of this randomised clinical trial over 12 weeks was to determine if the gradual transition (accompanied by calf muscle training), from conventional to minimalist running shoes 1) increased the risk of lower limb pain or injury and 2) improved lower limb muscle function (endurance, flexibility and power) in experienced distance runners. In addition, the effects of the transition on runner satisfaction were studied. Based on the evidence provided in this thesis, the study objectives as described in Section 1.3.2 (page 3) may be answered as follows:

> *To determine whether there were significant differences in lower limb injury incidence and pain, calf endurance, hamstring and calf muscle flexibility, lower limb muscle power, foot posture index, ROM and participants' satisfaction with the type of running shoes and performance between an experimental group that ran in minimalist shoes, and a control group that ran in conventional shoes.*

In this study, there were no significant differences between groups in injury incidence. There were significant interactions between groups over time for the outcome measures of total number of anatomical sites of pain (per week). Minimalist running shoes resulted in an initial increase in total number of anatomical sites of pain, specifically pain in the calf area. The running training programme used in this study was a slow transition while using minimalist shoes.

This was accompanied by a hopping programme (calf muscle training) that was performed by both groups. In addition, the experimental group showed significant changes in general satisfaction with comfort and support of shoes at week four compared to the control group. Furthermore, there were significant differences within the experimental group over time in general satisfaction with lower limb function at week 12. Total number of anatomical sites of pain and general satisfaction with comfort and support of shoes both showed unfavourable changes that reflect the initial disadvantages of running in minimalist running shoes. These initial disadvantages encompass the musculoskeletal and biomechanical adaptations that may potentially occur when transitioning from conventional into minimalist running shoes. General satisfaction with lower limb function showed favourable changes in the experimental group that reflected the benefits in satisfaction scores of running in minimalist running shoes once musculoskeletal and biomechanical adaptations reached a plateau. Thus, minimalist running shoes have both favourable as well as unfavourable factors. A trend (increase in experimental group from weeks two to week six, compared to the control group) appeared in the weekly incidence of self-reported pain, pain severity scores as well as anatomical sites of pain. However, these were trends only and while these findings might be of practical clinical relevance, they were not statistically significant.

> *To determine whether there were significant differences in lower limb injury incidence and pain, calf endurance, hamstring and calf muscle flexibility, lower limb muscle power, foot posture index, hallux ROM and participants' satisfaction with the type of running shoes and performance between groups over time.*

In this study, there were significant differences in: left calf endurance; average calf endurance; lower limb muscle power; left, right; average hallux plantarflexion ROM; left, right and average hallux dorsiflexion ROM over time. Therefore, both groups demonstrated improved calf endurance, lower limb muscle power and hallux plantarflexion and dorsiflexion ROM over time.

The results of this study support the notion that minimalist as well as conventional running shoes do not increase lower limb injury incidence in the lower limbs[84,110,114]. In addition, neither minimalist nor conventional running shoes improve lower limb muscle function in experienced distance runners over a period of 12 weeks. Furthermore, the transition does affect runner satisfaction. In conclusion, neither conventional nor minimalist running shoes appear to be superior when compared to each other. Moreover, there appears to be a period of adaptation following the transition from minimalist to conventional shoes. An initial increase in lower limb pain occurs during the transition period due to the potential musculoskeletal and biomechanical adaptations.

Based on the findings of this study, care should be taken when transitioning from conventional into minimalist running shoes, to avoid increased stresses on the musculoskeletal system that may result in potential pain and lower limb running related injuries. In addition, a runner should not transition from conventional into minimalist running shoes without a training programme. The transition must be gradual and take place over a period of between four to eight weeks. Runners need to be educated with regards to this important transition period when changing from conventional into minimalist running shoes. In addition, clinicians and coaches should be made aware of this training programme due to the increased popularity of minimalist running shoes and the musculoskeletal and biomechanical adaptations that potentially occur within the initial period of transitioning. Based on the findings in this study, modifications to the four week training programme, sample size and length of the study period are recommended to further evaluate the long-term effects of minimalist versus conventional running shoes on lower limb injury incidence, pain and muscle function in experienced distance runners.

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APPENDIX I

Informed Consent Form

Department of Health and Rehabilitation Sciences

Faculty of Health Sciences

Divisions of Communications Sciences and Disorders,
Nursing and Midwifery, Occupational Therapy,
Physiotherapy

F45 Old Main Building, Groote Schuur Hospital,

A study to determine minimalist versus conventional running shoes: Effects on lower limb injury incidence, pain and muscle function in experienced distance runners

Dear Participant

My name is Charlene Marshall. I am a physiotherapist currently pursuing a Masters in Physiotherapy at the University of Cape Town (UCT). The requirement of the postgraduate degree is to conduct and implement a research study in a field of special interest. I will be conducting a research study to determine the effects of training in minimalist and conventional running shoes on the development of running injuries and muscle function in experienced distance runners. This study has been given Ethical Approval by the Faculty of Health Sciences Human Research Ethics Committee, UCT.

Running shoes are a must-have for long distance running. The design of running shoes is constantly changing. Minimalist running shoes are gaining popularity among runners as they are thought to mimic barefoot running, but the short- and long-term effects of different footwear are uncertain. We aim to find out whether different types of running shoes influence the type and number of running injuries during training, and also whether the shoes change your running style and muscle function. This study may help to give practical advice to runners in future about the best shoes to buy for training and competition, and will also help health care professionals give appropriate advice when recommending different shoe types to runners.

We also hope to find out if shoes influence the risk for injury, and the information from this study will hopefully contribute to safer participation in distance running.

You will be asked to attend a total of five appointments, lasting approximately one hour each, over the course of 12 weeks. For each session, you will be required to travel to the Health Centre on Cape Road in Mill Park at your own cost.

This study will be supervised by Dr Theresa Burgess, Professor Martin Schwellnus, and Candice Hendricks from UCT. Please take time to read this form thoroughly before signing.

On the first appointment:

The testing procedure will be explained and any questions will be addressed. You will be asked to complete two questionnaires regarding your running activities as well as your sport, injury and general health history. Anthropometric measurements including weight, height, body mass index (BMI) and body fat percentage will be taken. BMI is a measure of body fat based on height and weight.

Two screening tests will be performed to determine whether you may be included in the study. The first test will measure the length of both of your legs. If there is a difference in your leg length of more than 15 mm, you will be excluded from the study. The second test will measure your Q-angle. This is the knee angle between your hip and shin bone. An angle of more than 14° will exclude you from the study. The presence of any of these factors increases your risk of sustaining an injury and that is why you may be excluded from the study if any one of these tests is positive.

Once the screening tests are completed all of the testing procedures will be explained to make sure that you understand exactly what is expected of you. This is called familiarisation. You will also be required to complete a weekly training log with regards to your training schedules during testing. At the end of each week, the information required will be completed in a computerised form on Vula (online interaction website). You will be shown how to complete it correctly. You will then be allocated to either an experimental or a control group. This will be done by ranking your years of running experience and age. If you are in the experimental group, you will receive a pair of minimalist running shoes and if you are in the control group, you will continue to run in your own conventional running shoes.

On the second appointment:

On the second meeting (five days after the first meeting), baseline measurements will be taken. These measurements include the following: Calf endurance, muscle flexibility, lower limb muscle power, foot posture index, satisfaction with the type of running shoes and performance, hallux range of motion and injury incidence. Foot posture index refers to the position of your foot in a relaxed standing position. Hallux range of motion refers to the amount of movement of your big toe.

- Calf endurance will be measured with the calf raise test. You will be video recorded during this test. You will stand on the edge of a step with the ball of your foot on the step. One foot will be tested at a time. You will then be instructed to perform a full calf raise and lower your heel back onto the step. One calf raise will be performed per second. A metronome will be used to make sure that you perform the calf raises at the correct time interval. The test will be stopped once you cannot perform three full calf raises in a row or once you stop voluntarily due to fatigue. The Borg test will be used to rate your level of fatigue. If you report a number between 17 to 20, the test will be terminated immediately. The average number of calf raises performed per leg will be recorded.
- Flexibility of your hamstrings and calf muscles will be tested on both legs. Calf flexibility will be measured using the forward lunge test. A tape measure will be positioned along the floor with a vertical line along the wall. You will be instructed to keep your foot aligned along the tape measure and your heel flat against the floor at all times. You will then lunge forwards until your knee touches the vertical line drawn on the wall. You may hold onto the wall for support if required. Hamstring flexibility will be measured using the active knee extension test. You will be positioned on your back. A strap will be secured over your pelvis to secure it in place. Your thigh of the leg to be tested will then be lifted up towards the ceiling until it is in a vertical position. A horizontal bar will be positioned above you to ensure your leg stays in this position during testing. You will then be instructed to lift up your heel towards the ceiling (straighten your leg) until you cannot anymore. The investigator will then measure the flexibility of your hamstring with a goniometer. This will be done three times on both legs and an average will be recorded.
- Lower limb muscle power will be assessed three times using the vertical jump test. You will be required to stand against a wall and extend your arm above your head as high as possible. This height will then be recorded. Thereafter, you will squat down to the ground next to the wall. You will then be instructed to jump as high as possible and touch the wall. This height will then be measured and the difference between the two heights will be recorded.

- Foot posture will be measured using the foot posture index. You will be required to stand in a relaxed position with both of your feet flat on the floor. Your arms will rest along your sides and you will be required to stand still while the investigator assesses the posture of both your left and right feet. You will be instructed to look straight ahead of you and not move throughout the test. It will take roughly two minutes to complete the test. The investigator will observe your foot posture and score each category accordingly.
- Satisfaction with the type of running shoes and performance will be measured using a satisfaction questionnaire. The questionnaire consists of twelve questions relating to different aspects of your shoes and training during the study period. You will be required to mark your appropriate response to the question with an ‘X’.
- Hallux range of motion will be measured with a goniometer while you are positioned on your back. The investigator will move your big toe up and down, as far as possible, while you relax. This will be performed three times on both the left and right and an average will be recorded.
- The training log consists of columns containing information regarding injury, total distance covered, total time taken to cover the distance, session rate of perceived exertion (RPE) and the brief pain inventory (BPI) scores. You will be required to complete this training log with totals per week on Vula, for the total 12 weeks of the study. Presence of pain including location and severity must be completed in the appropriate column. Total distance in kilometres, total time taken to complete the distance in minutes, session RPE and the BPI columns must all be completed correctly. Session RPE is a score of how difficult you felt your training was for the week. The scores range from 0-10, where 0 is rest. The brief pain inventory refers to the worst pain, least pain, average pain and pain felt at present, which you felt during the week. Scores range between 0-10, where 0 is no pain.

Between the Second and Third Appointment

If you are in the experimental group, you will be required to undergo a four week training programme. This training programme is aimed at conditioning your body and muscles to the new stressors and forces arising from running in minimalist running shoes.

A copy of the programme will be given to you. You will be asked to use this training programme to become accustomed to the new type of shoes you will be running in. It is very important that you follow this training programme exactly, otherwise you may be at an increased risk of injury. If you are in the control group, you will be required to complete only the hopping sessions of the four week training programme. You will not be required to follow any other sections of the programme as you do not require conditioning to run in your conventional shoes, as your body is already used to running in these shoes. You will be required to perform these hopping sessions daily, four times per week, after you have completed your normal daily training schedule. After the four week training programme, you will be asked to complete a compliance checklist.

On Subsequent Appointments

If you are in the experimental group, you will continue with your normal running schedule after the four week training programme has been completed along with the control group. After every four weeks, all previous tests will be performed on both groups. This will continue up until 12 weeks into the study.

Potential Risks:

- The vertical jump test involves a maximal quadriceps contraction. The calf raise test involves a repeated gastrocnemius and soleus contraction. The risk of these contractions is similar to that of performing unaccustomed exercise including painful and stiff muscles. Injury will be minimised by supervising the procedure and familiarisation and demonstrations will be provided before you take part in the study. A warm-up will also be conducted before testing to reduce the risk of musculoskeletal injury.
- The flexibility test involves moving your ankle joint and hamstrings up until the onset of a stretch sensation is felt. This may pose a risk of a possible over stretch of the muscles around your ankle joint and the hamstrings. These risks will be minimized by familiarising you prior to testing and stopping the movement once the stretch sensation commences.
- The hallux range of motion test involves moving the metatarsophalangeal joint to end of range. This may pose a risk of possible over stretch of the muscles around this joint. These risks will be minimized by familiarising you prior to testing and stopping the movement once the stretch sensation commences.
- You may be exposed to the risk of sustaining a running related injury during the four week training programme, as muscles will be conditioned during this programme. In addition, if you are in the control group, you may not be used to performing hopping. This may increase your risk of sustaining a musculoskeletal injury. These risks will be minimized by familiarising you with the training programme and hopping sessions prior to the commencement of the study.
- You will not be used to running in minimalist running shoes and your muscles will not be conditioned to the different stresses and forces required with these types of shoes prior to the study. You could therefore obtain running related injuries. These risks will be minimised by implementing a four week training programme for the experimental group. The four week training programme has been designed to familiarise you with minimalist shoes and to reduce the potential risk for injury due to running in unfamiliar shoes.
- Furthermore, everyone taking part in this study will be at risk for developing injuries due to conventional training for endurance running. You will be asked to avoid strenuous training and competition for the duration of the study period to minimise the risk of running related injuries.

Benefits:

The study aims to test the effects of conventional versus minimalist running shoes on lower limb injury incidence, pain, satisfaction and muscle function in experienced distance runners. You will be informed of the results of the study, thereby gaining knowledge which will be of benefit to you regarding future purchasing of running shoes. You will also receive your anthropometry measurements and an information sheet containing a four week training programme to begin running in minimalist running shoes.

Unfortunately, no financial compensation is available for participation in this study, however the experimental group will get to keep their minimalist running shoes and the control group will receive discount on purchase of minimalist running shoes from a local manufacturer as well as a copy of the four week training programme at the end of the study.

Questions or Concerns:

You will be advised regarding treatment if an injury is sustained during the study period while taking part in normal training. You will be referred to the appropriate health professional. Please note that UCT does offer a no-fault insurance that will cover all participants in the event that something may go wrong.

The insurance will not cover injuries sustained as a result of normal running training. This insurance will provide prompt payment of compensation for any trial-related injury according to the Association of the British Pharmaceutical Industry guidelines (1991). These guidelines recommend that UCT, without any legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study investigators immediately of any injuries during the trial, whether they are research-related or other related complications.

UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected. If at any time you have any questions about the study, please feel free to contact me. You are assured that all inquiries will remain confidential.

Charlene Marshall 0731776330

Should you have and further queries, feel free to contact:

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By placing your signature below, it serves as confirmation that you have had adequate time to read through and have understood the consent form and that you are willing to participate in this study. You have the right to withdraw at any time without any penalty, you may ask questions at any time during the study and all the information recorded will be confidential. Your signature is further confirmation that you are aware of the possible risks involved in this study and that participating in this study is purely voluntarily.

______________________	______________________	______________
Signature of Volunteer	Name (Please Print)	Date
______________________	______________________	______________
Signature of Witness	Name (Please Print)	Date
______________________	______________________	______________
Signature of Investigator	Name (Please Print)	Date

APPENDIX II

Medical and Physical Activity Questionnaire[67,133]

Department of Health and Rehabilitation Sciences

Faculty of Health Sciences

Divisions of Communications Sciences and Disorders, Nursing and Midwifery, Occupational Therapy, Physiotherapy

Instructions:

- This questionnaire consists of 7 pages
- Please read each question carefully as it is important that we obtain accurate information.
- Please place information in the appropriate text box e.g. Date of Birth 12/03/1983 Day/Month/Year
- If a question is asked, please place an **'x'** in the appropriate text box. e.g. What is your favourite colour?

☐ Blue ☐ Green ☒ Red ☐ Yellow

- Please answer all questions as truthfully as possible. All personal information will be kept strictly confidential.
- If you have any questions do not hesitate to contact us on:

Charlene Marshall	0731776330
Dr Theresa Burgess	021 406 6171
Ms Candice Hendricks	021 406 6382
Prof Martin Schwellnus	martin.schwellnus@uct.ac.za

Name: ______________________ **Surname**: _______________________

Age: ________________________ **Date of Birth**: ___/____/_____

- **<u>Injury History</u>**

Have you been injured in the past 3 months? Yes ☐ No ☐

If so, what date did you become aware of the injury?

____

Which side of your body was the injury? Left ☐ Right ☐

Where was/is the injury? i.e.: Left leg, left hand, right knee

____

What structures are involved? Muscle ☐ Tendon ☐

Ligament ☐ Bone ☐ Joint ☐

Please indicate the severity of the injury

☐ **I experience symptoms after exercise (Grade 1)**

☐ **I experience symptoms during exercise but it doesn't interfere with the exercise (Grade 2)**

☐ **I experience symptoms during exercise that may interfere with training/competition (Grade 3)**

☐ **It is so painful that I may not be able to train/compete (Grade 4)**

Is the injury long standing or acute? Please specify a time frame

____

How did the injury happen? i.e.: During training, a game, other activity

____

Did you see a Doctor or physiotherapist for the injury? If so, what treatment did you receive?

Yes ☐ No ☐

____

Have you ever been diagnosed with the following:

☐ Leg length discrepancy

☐ Increased Q-angle

☐ Excessive pronation

☐ Lower limb alignment abnormalities

- **<u>Medical History</u>**

Do you have any previous surgical history?

Cardiac Surgery: yes ☐ no ☐

Spinal Surgery: yes ☐ no ☐

Other: yes ☐ no ☐

Fractures: yes ☐ no ☐

Please specify where:

Have you been ill in the past 3 weeks? yes ☐ no ☐

If so, what illness was/is it? i.e. cold, flu, measles:

If yes, did you take any medication for the illness? What is the name of the medication?

Is there any medication that you regularly take to manage pain/injuries Eg: Paracetamol, anti-inflammatories? yes ☐ no ☐

If yes, please specify what type of medication and how often you take it

Are you on any chronic medication? yes ☐ no ☐

If yes, Please specify

Please make an X in the appropriate box if you have ever been diagnosed with any of the following conditions by a medical doctor?

Coronary Heart Disease	☐	Asthma	☐
Diabetes	☐	Rheumatoid Arthritis	☐
Thyroid Disease	☐	Renal Disease	☐
Allergies	☐	High Blood Pressure	☐

Tuberculosis ☐

Osteoarthritis ☐

High Cholesterol ☐

Vascular diseases ☐

Arteriosclerosis ☐

Cryoglobinaemia ☐

Osteoporosis ☐

Cancer ☐

Stroke ☐

Impaired sensation ☐

Raynaud’s disease ☐

Other ☐

Other, please specify: ____

- **Running Information**

How often do you run per week?

On average, how many minutes or hours do you train per day?

____

On average, for how many hours per week do you train?

____

On average, how far do you run per training day? (In Kilometres)

____

On average, how far do you run per week? (In Kilometres)

____

How many years have you been running for?

Do you take part in 10km races? If so, what is your best time?

____

Do you take part in half marathons (21.1km)? If so, what is your best time?

____

Do you take part in full marathons (Anything over 42km)? If so, what is your best time and what was the distance that you ran?

____

Will you be taking part in any races of more than 21.1 km during the 12 weeks of the study period?

____

What type of surface do you train on? i.e. tar, gravel etc

____

Do you stretch after running on a regular basis?

yes ☐ no ☐

If yes, what types of stretches do you do? (E.g. calf stretches)

____

What brand of running shoes do you run in?

____

What type of running shoes do you run in?

☐ soft neutral shoe
☐ light racing shoe
☐ other: ____
☐ mild anti-pronation shoe
☐ minimalist/barefoot shoe
☐ motion control shoe
☐ unknown/not sure

Do you follow a healthy diet during your training?

____

How many meals per day do you eat?

____

Please indicate using the numbered sporting activity key, what physical and extra curricula activities you participate in. Please state the duration of time and how often during the week you participate in this activity. If none of the examples below are applicable please fill in your activity in the space provided.

Sporting activity Key:

1. Hockey	8. Canoeing	15. Horse riding
2. Aerobics/ Step	9. Dancing	16. Swimming
3. Martial arts	10. Skating	17. Cycling
4. Volleyball	11. Jogging	18. Walking
5. Strength/Resistance Training	12. Squash	19. Basketball
6. Hiking	13. Tennis	20. Soccer
7. Golf	14. Badminton	21. Athletics

Type of sport	**Months per year (months/year)**	**Number of sessions per week**	**Duration of each session (hour : min)**	**Total hours per week (hours/week)**

Participants Contact Details:

Name: ______________________________________

Cell number: ______________________________________

Home number: _____________________________________

E-mail: ___________________________________

Participants Signature:______________________ Date:________________

APPENDIX III

Physical Activity Readiness Questionnaire[67]

Department of Health and Rehabilitation Sciences

Faculty of Health Sciences

Divisions of Communications Sciences and Disorders,
Nursing and Midwifery, Occupational Therapy,
Physiotherapy

Has a Doctor said you have a heart condition and that you should only do physical activity recommended by a Doctor?

yes ☐ no ☐

Do you feel pain in your chest when you do physical exercise?

yes ☐ no ☐

In the past month, have you had chest pain when you were not doing physical exercise?

yes ☐ no ☐

Do you ever lose consciousness or do you lose your balance because of dizziness?

yes ☐ no ☐

Do you have a joint or bone problem that may be made worse by a change in your physical activity?

yes ☐ no ☐

Is a physician currently prescribing medication for your blood pressure or heart condition?

yes ☐ no ☐

Do you know of any other reason why you should not do/increase physical activity?

yes ☐ no ☐

APPENDIX IV

Data Collection Forms

Anthropometry

Participants Name:______________________________

Body mass ___________

Stature ___________

BMI ___________

Dominant leg ___________

Sum of 7 skinfolds __________

Predicted % body fat __________

Lean body mass __________

Skinfold measurements (mm)	
Triceps	
Biceps	
Sub-scapular	
Supra-iliac	
Thigh	
Calf	
Abdominal	

Calf Endurance: Calf Raise Test

Time (weeks)	Number of calf raises						Average number of calf raises	
Repetition	1		2		3			
	Left	Right	Left	Right	Left	Right	L	R
0								
4								
8								
12								

Muscle Flexibility Test

Time (weeks)	Degrees of ROM of popliteal angle						Average range (degrees)	
Repetition	1		2		3			
Hamstring	Left	Right	Left	Right	Left	Right	L	R
0								
4								
8								
12								

Time (weeks)	Distance from big toe to wall (cm)						Average distance (cm)	
Repetition	1		2		3			
Calf flexibility	Left	Right	Left	Right	Left	Right	L	R
0								
4								
8								
12								

Muscle Power: Vertical Jump Test

Time (weeks)	Standing reach height (cm)	Vertical jump height (cm)			Average	Score (*)
		Attempt 1	Attempt 2	Attempt 3		
0						
4						
8						
12						

*Difference in standing reach height and best jump height = score

Foot Posture: Foot Posture Index

WEEK: 0			
FACTOR	**PLANE**	**SCORE**	
		Left **(-2 to +2)**	**Right** **(-2 to +2)**
Talar head palpation	*Transverse*		
Curves above and below the lateral malleolus	*Frontal/transverse*		
Inversion/eversion of the calcaneus	*Frontal*		
Prominence in the region of the talonavicular joint	*Transverse*		
Congruence of the medial longitudinal arch	*Sagittal*		
Abduction/adduction fore-foot on rear-foot	*Transverse*		
TOTAL			

WEEK: 4			
FACTOR	**PLANE**	**SCORE**	
		Left **(-2 to +2)**	**Right** **(-2 to +2)**
Talar head palpation	*Transverse*		
Curves above and below the lateral malleolus	*Frontal/transverse*		
Inversion/eversion of the calcaneus	*Frontal*		
Prominence in the region of the talonavicular joint	*Transverse*		
Congruence of the medial longitudinal arch	*Sagittal*		
Abduction/adduction fore-foot on rear-foot	*Transverse*		
TOTAL			

WEEK: 8			
FACTOR	**PLANE**	**SCORE**	
		Left **(-2 to +2)**	**Right** **(-2 to +2)**
Talar head palpation	*Transverse*		
Curves above and below the lateral malleolus	*Frontal/transverse*		
Inversion/eversion of the calcaneus	*Frontal*		
Prominence in the region of the talonavicular joint	*Transverse*		
Congruence of the medial longitudinal arch	*Sagittal*		
Abduction/adduction fore-foot on rear-foot	*Transverse*		
TOTAL			

WEEK: 12			
FACTOR	**PLANE**	**SCORE**	
		Left **(-2 to +2)**	**Right** **(-2 to +2)**
Talar head palpation	*Transverse*		
Curves above and below the lateral malleolus	*Frontal/transverse*		
Inversion/eversion of the calcaneus	*Frontal*		
Prominence in the region of the talonavicular joint	*Transverse*		
Congruence of the medial longitudinal arch	*Sagittal*		
Abduction/adduction fore-foot on rear-foot	*Transverse*		
TOTAL			

Reference values:

Normal: 0 to +5

Pronated: +6 to +9, Highly pronated: 10+

Supinated: -1 to -4, Highly supinated: -5 to -12 [92,106,115]

Participant Name: ____

Current Average Weekly Training (km):______________________

Satisfaction Questionnaire

Instructions: Experimental/Minimalist Group

All questions should be answered as accurately as possible. The questions are set out so that you may answer on a scale of 1-5.

To indicate your answers make an X in the desired block.

1. Are you satisfied with your running shoes at the moment?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

2. How do you feel about your current training status in terms of the frequency of your running training this week?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

3. How do you feel about your current training status in terms of the intensity of your training runs this week?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

4. How do you feel about your current training status in terms of the duration of your training runs this week?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

5. How do you feel about your current performance level in terms of the total time and kilometres run this week?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

6. Are you satisfied with your current general lower limb flexibility (muscle length in both of your legs)?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

7. Are you satisfied with your current general lower limb muscle strength (strength of the muscles in both of your legs)?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

8. Are you satisfied with your general lower limb comfort during running?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

9. Are you satisfied with your foot comfort during running?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

10. Are you satisfied with the support that your running shoes offer you?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

11. Are you satisfied with the cushioning that your running shoes offer you?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

12. How do you feel about continuing to run in minimalist shoes?				
Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

Participant Name: ________________________________

Current Average Weekly Training (km):______________________

Satisfaction Questionnaire

<u>Instructions: Control/Conventional Group</u>

All questions should be answered as accurately as possible. The questions are set out so that you may answer on a scale of 1-5.

To indicate your answers make an X in the desired block.

1. Are you satisfied with your running shoes at the moment?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

2. How do you feel about your current training status in terms of the frequency of your running training this week?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

3. How do you feel about your current training status in terms of the intensity of your training runs this week?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

4. How do you feel about your current training status in terms of the duration of your training runs this week?				
Very satisfied	**Satisfied**	**Unsure**	**Dissatisfied**	**Very dissatisfied**
5	**4**	**3**	**2**	**1**

5. How do you feel about your current performance level in terms of the total time and kilometres run this week?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

6. Are you satisfied with your current general lower limb flexibility (muscle length in both of your legs)?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

7. Are you satisfied with your current general lower limb muscle strength (strength of the muscles in both of your legs)?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

8. Are you satisfied with your general lower limb comfort during running?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

9. Are you satisfied with your foot comfort during running?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

10. Are you satisfied with the support that your running shoes offer you?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

11. Are you satisfied with the cushioning that your running shoes offer you?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

12. How do you feel about continuing to run in conventional running shoes?

Very satisfied	Satisfied	Unsure	Dissatisfied	Very dissatisfied
5	4	3	2	1

Hallux Range of Motion

Time (weeks)	Hallux ROM (degrees)												Average ROM (degrees)			
	Dorsiflexion						Plantarflexion						Plantarflexion		Dorsiflexion	
Repetition	1		2		3		1		2		3					
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
0																
4																
8																
12																

Injury Report Form

Time (weeks)	Injured	Type of injury	Recurring injury (yes or no)	Mechanism of injury	Location of injury	Number of training days missed
0						
4						
8						
12						

APPENDIX V

Example of the Online Training Log

Part 1 of 2 – Training logbook

Question 1:

In the previous week, have you experienced any pain?

yes ☐ no ☐

Question 2:

What has been your total running mileage (kilometres) for the past week?

Question 3:

What has been your total running time (minutes) for the past week?

Question 4:

On average, how hard were your training sessions this past week?

- ☐ A. 0 - Rest
- ☐ B. 1 - Really easy
- ☐ C. 2 - Easy
- ☐ D. 3 - Moderate
- ☐ E. 4 - Sort of hard
- ☐ F. 5 - Hard
- ☐ G. 6 -
- ☐ H. 7 - Really hard
- ☐ I. 8 -
- ☐ J. 9 - Really, really hard
- ☐ K. 10 - Just like my hardest race

Part 2 of 2 – Brief pain inventory[33,74]

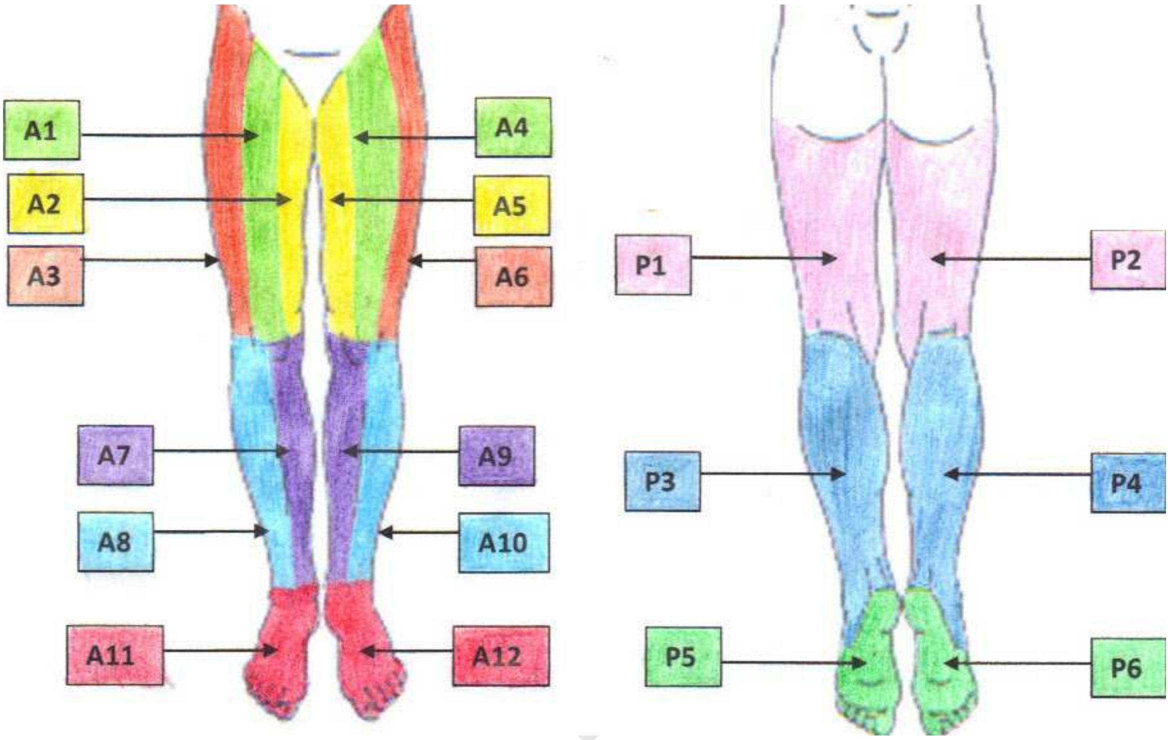
Question 1:

Throughout our lives, most of us have had pain from time to time (such as minor headaches, sprains and toothaches). Have you had pain other than these everyday kinds of pain during the last week?

yes ☐ no ☐

Question 2:

If you answered yes to the above question, please state in which areas you are currently experiencing pain and mark the areas which are the most painful with an X (e.g. A6, P2).



A1 – Right midthigh
A2 – Right medial thigh
A3 – Right lateral thigh
A4 – Left midthigh
A5 - Left medial thigh
A6 - Left lateral thigh
A7 - Right medial calf
A8 – Right lateral calf
A9 - Left medial calf
A10 - Left lateral Calf
A11 – Right anterior foot
A12 – Left anterior foot

P1 –Left posterior thigh
P2 – Right posterior thigh
P3 – Left posterior calf
P4 – Right posterior calf
P5 – Left posterior foot
P6 – Right posterior foot

Question 3:

Please select the one number that best describes your pain at its WORST in the past week.

- ○ A. 0 - No Pain
- ○ B. 1
- ○ C. 2
- ○ D. 3
- ○ E. 4
- ○ F. 5
- ○ G. 6
- ○ H. 7
- ○ I. 8
- ○ J. 9
- ○ K. 10 - Pain as bad as you can imagine

Question 4:

Please select the one number that best describes your pain at its LEAST in the past week.

- ○ A. 0 - No Pain
- ○ B. 1
- ○ C. 2
- ○ D. 3
- ○ E. 4
- ○ F. 5
- ○ G. 6
- ○ H. 7
- ○ I. 8
- ○ J. 9
- ○ K. 10 - Pain as bad as you can imagine

Question 5:

Please select the one number that best describes your pain ON AVERAGE in the past week.

- ○ A. 0 - No Pain
- ○ B. 1
- ○ C. 2
- ○ D. 3
- ○ E. 4
- ○ F. 5
- ○ G. 6
- ○ H. 7
- ○ I. 8
- ○ J. 9
- ○ K. 10 - Pain as bad as you can imagine

Question 6:

Please select the one number that best describes how much physical pain you are experiencing RIGHT NOW.

- ○ A. 0 - No Pain
- ○ B. 1
- ○ C. 2
- ○ D. 3
- ○ E. 4
- ○ F. 5
- ○ G. 6
- ○ H. 7
- ○ I. 8
- ○ J. 9
- ○ K. 10 - Pain as bad as you can imagine

APPENDIX VI

Borg Scale: Rate of Perceived Exertion

6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

APPENDIX VII

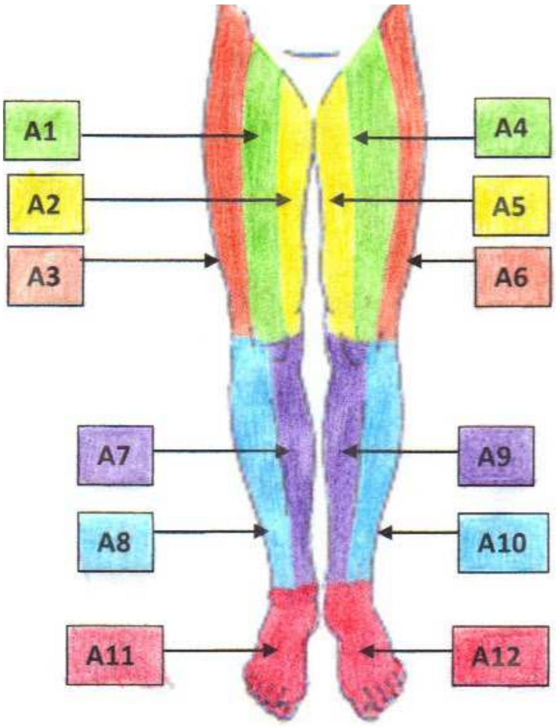
Brief Pain Inventory[33,74]

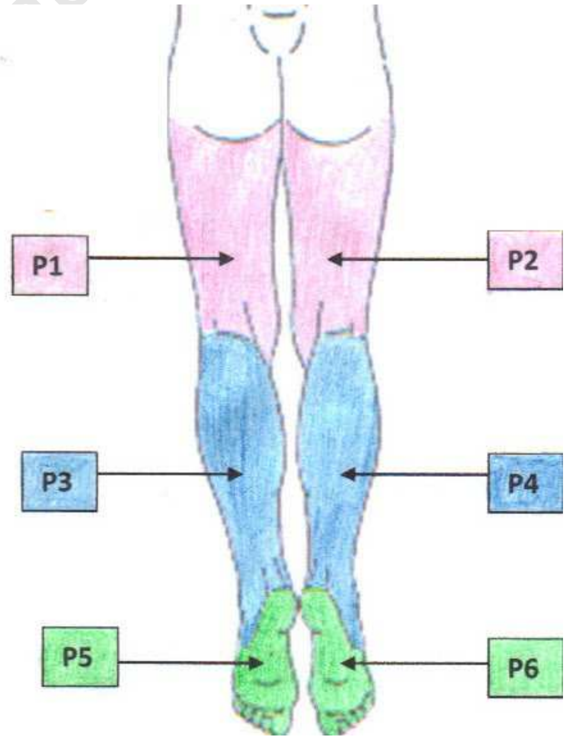
Name:____________________ **Date:**_______________

1. Throughout our lives, most of us have had pain from time to time (such as minor headaches, sprains, and toothaches). Have you had pain other than these everyday kinds of pain during the last week?

yes ☐ no ☐

2. If you answered yes to the above question, please state in which areas you are currently experiencing pain and mark the areas which are the most painful with an X (e.g. A6, P2).





A1 – Right midthigh

A2 – Right medial thigh

A3 – Right lateral thigh

A4 – Left midthigh

A5 - Left medial thigh

A6 - Left lateral thigh

A7 - Right medial calf

A8 – Right lateral calf

A9 - Left medial calf

A10 - Left lateral Calf

A11 – Right anterior foot

A12 – Left anterior foot

P1 –Left posterior thigh

P2 – Right posterior thigh

P3 – Left posterior calf

P4 – Right posterior calf

P5 – Left posterior foot

P6 – Right posterior foot

3. Please rate your pain by circling the one number that best describes your pain at its ***worst*** in the last week.

0	1	2	3	4	5	6	7	8	9	10
No										Pain as bad as
Pain										you can imagine

4. Please rate your pain by circling the one number that best describes your pain at its ***least*** in the last week.

0	1	2	3	4	5	6	7	8	9	10
No										Pain as bad as
Pain										you can imagine

5. Please rate your pain by circling the one number that best describes your pain on the ***average.***

0	1	2	3	4	5	6	7	8	9	10
No										Pain as bad as
Pain										you can imagine

6. Please rate your pain by circling the one number that best describes how much pain you have ***right now.***

0 1 2 3 4 5 6 7 8 9 10

No Pain | Pain as bad as you can imagine

*Scoring: Pain Severity Score = Mean of items 3-6 (pain at its worst, least, average and present) [33]

APPENDIX VIII

Session RPE[40,44,48,80]

Score	**Session RPE**
0	Rest
1	Really easy
2	Easy
3	Moderate
4	Sort of hard
5	Hard
6	
7	Really hard
8	
9	Really, really hard
10	Just like my hardest race

74

APPENDIX IX

Foot Posture Index[92,106,115]

Rear-foot Score	**-2**	**-1**	**0**	**1**	**2**
Talar head palpation	Talar head palpable on lateral side/but not on medial side	Talar head palpable on lateral side/ slightly palpable on medial side	Talar head equally palpable on lateral and medial side	Talar head slightly palpable on lateral side/ palpable on medial side	Talar head not palpable on lateral side/but palpable on medial side
Curves above and below the malleoli	Curve below the malleolus either straight or convex	Curve below the malleolus concave, but flatter/more shallow than the curve above the malleolus	Both infra and supra malleolar curves roughly equal	Curve below malleolus more concave than curve above malleolus	Curve below malleolus markedly more concave than curve above malleolus
Calcaneal inversion/eversion	More than an estimated 5° inverted (varus)	Between vertical and an estimated 5° inverted (varus)	Vertical	Between vertical and an estimated 5° everted (valgus)	More than an estimated 5° everted (valgus)
Fore-foot Score	**-2**	**-1**	**0**	**1**	**2**
Talonavicular congruence	Area of talonavicular joint markedly concave	Area of talonavicular joint slightly, but definitely concave	Area of talonavicular joint flat	Area of talonavicular joint bulging slightly	Area of talonavicular joint bulging markedly
Medial arch height	Arch high and acutely angled towards the posterior end of the medial arch	Arch moderately high and slightly acute posteriorly	Arch height normal and concentrically curved	Arch lowered with some flattening in the central portion	Arch very low with severe flattening in the central portion-arch making ground contact
Fore-foot abduction/adduction	No lateral toes visible. Medial toes clearly visible	Medial toes clearly more visible than lateral	Medial and lateral toes equally visible	Lateral toes clearly more visible than medial	No medial toes visible. Lateral toes clearly visible

APPENDIX X

Four Week Training Programme[22]

Four week training programme to be followed by the experimental group

	Run (minutes)	Reps	Walk (minutes)	Hop	Days per week
Week 1	10	2	5	30	4
Week 2	15	2	5	40	4
Week 3	35	1	0	55	4
Week 4	45	1	0	70	4

Hopping sessions to be followed by the control group for the first four weeks

	Hop	Days per week
Week 1	30	4
Week 2	40	4
Week 3	55	4
Week 4	70	4

APPENDIX XI

Compliance Checklist with Four Week Training Programme

a) Did you follow the training programme exactly for the 4 weeks?

yes ☐ no ☐

b) Did you partake in any other type of running (other than road running) in other running shoes during this four week training programme?

yes ☐ no ☐

c) Did you remember to complete the hopping sessions per day as required?

yes ☐ no ☐

APPENDIX XII

Reliability Study: Intra-Rater Reliability of Parameters Required for Minimalist versus Conventional Running Shoes: The Effect on Lower Limb Injury Incidence, Pain and Muscle Function in Experienced Distance Runners[102]

XII.I BACKGROUND

Intra-rater reliability is the ability of an examiner to accurately perform a specific testing method repeatedly, over a period of time. It is essential in clinical practice as independent practitioners commonly utilise tests to re-evaluate and determine a specific patient's progress in performance, injury healing and response to treatment protocols.

XII.II AIM

The aim of this reliability study was to determine:

1. The reliability of the foot posture index test on both lower limbs.
2. The intra-rater reliability for the hand held goniometric measurement of the popliteal angle (active knee extension test, hamstring flexibility), hallux plantarflexion and dorsiflexion ROM on both lower limbs.
3. The intra-rater reliability for performing and measuring the ankle lunge test using a tape measure to measure calf flexibility on both lower limbs.

XII.III METHODS

XII.III.I PARTICIPANTS

Six male (n = 6) participants took part in the study. The participants were experienced distance runners between 18 and 50 years of age.

XII.III.II TESTING PROCEDURE

The six participants were requested to attend three assessment sessions over a period of three consecutive days, at a physiotherapy practice situated on Cape Road in Mill Park, Port Elizabeth. Each participant was measured by the investigator at every assessment session. Therefore three assessments per participant were conducted. Each assessment included the completion of the foot posture index test and measurement of skin-folds, popliteal angle (active knee extension test), hallux plantarflexion and dorsiflexion hallux ROM, as well as the ankle lunge test (calf flexibility) on both lower limbs per participant. In addition to this, participants attended a trial of the familiarisation session, completed week one of the four week training programme and week one of the online training log (feasibility testing).

a) Anthropometric Measurements

Body mass was recorded using a calibrated scale (Safeway, Ultra-portable personal scale) and stature was recorded using a stadiometer. Body fat was expressed as the sum of seven skin folds (biceps, triceps, subscapular, suprailiac, calf, thigh and abdomen)[113].

b) Foot Posture: Foot Posture Index

The standing foot posture was measured using the foot posture index. Participants stood in a relaxed stance position with double limb support, and were instructed to stand still, look straight ahead and keep their arms at their sides.

During the assessment, the investigator ensured that participants did not look around or swivel at any point. The foot posture index evaluates six criteria on each foot, namely: talar head palpation; supra- and infra-malleolar curvature; calcaneal frontal plane position; prominence in the region of the talonavicular joint; congruence of the medial longitudinal arch; and adduction/abduction of the fore-foot on the rear-foot. Each criterion was scored on a scale of -2, -1, 0, +1, or +2 (Appendix IX). The results were then combined into a summative score and categorised to define the type of foot posture as follows: highly supinated (-12 to -5); supinated (-4 to -1); neutral (0 to +5); pronated (+6 to +9); and highly pronated (10+) (Appendix IX). This test was performed once on each foot. The reliability and validity of this test has been previously established[92,106,115].

c) Hamstring Muscle Flexibility

The active knee extension test was used to measure hamstring flexibility. Participants were positioned in supine on a plinth with the ankle of the test leg in a relaxed position. The non-test leg was strapped to the plinth with a velcro strap to stabilise the pelvis and to prevent flexion of the non-test leg during testing. A velcro strap was also positioned over the pelvis to increase stability. A stabilisation board that consisted of two vertical bars on either side of the plinth connected by a horizontal bar at 45 cm was used to ensure that the hip position of the test leg was maintained at 90° of hip flexion during the measurement. Participants were instructed to actively extend the knee while keeping the foot in a relaxed position to minimise the influence of the gastrocnemius muscle as well as neural tension in the lower limb. Participants were instructed to extend their knee until the onset of a stretch sensation was felt. When final extension was reached, the investigator supported the calf and measured the degree of knee extension. A goniometer was used to measure the popliteal angle. The fulcrum was placed on the lateral epicondyle of the femur; the stationary arm was aligned with the lateral midline of the thigh with the greater trochanter as reference point; and the moving arm was aligned with the lateral midline of the fibula with the lateral malleolus as the reference point. Participants performed three repetitions on each leg, and the average was recorded[8,38,64,73,141]. The reliability and validity of this test has been previously established[8,38,64,73,141].

d) Hallux Range of Motion

Hallux plantarflexion and dorsiflexion ROM was measured passively using a hand-held goniometer. Participants were positioned in supine on a plinth, and were required to relax throughout the testing procedure. The goniometer was positioned with the fulcrum placed over the centre of the first metatarsophalangeal joint; the stationary arm was aligned with the proximal phalanx; and the moving arm was aligned with the shaft of the first metatarsal. The investigator passively dorsiflexed and plantarflexed the hallux of each foot to the end of range. End of range was reached once the hallux reached full range (bony end feel) and no pain was felt by the participant. Each measurement was performed three times on the right and left hallux, and an average was recorded. The reliability and validity of this test has been previously established[4,12,88].

e) Calf Muscle Flexibility

The ankle lunge test was performed to measure the flexibility of the soleus complex. Participants were barefoot and were required to perform weight bearing dorsiflexion by lunging forward, with the knee beyond the toes. Participants positioned the foot so that a line drawn through the first toe and heel were aligned on a tape measure on the floor. The 0 cm point was positioned at the junction of the floor and wall. A vertical line was then drawn up the wall in line with the tape measure. The investigator held the participant's heel to ensure contact was maintained with the floor at all times, and to manually lock the subtalar joint so that it remained in neutral throughout the test. Participants were instructed to lunge forward so that the knee touched the vertical line on the wall. The leg which was not being tested was permitted to rest on the floor. Participants were permitted to hold onto the wall for support if needed. Participants performed three repetitions on each leg, and the average distance from the tip of the first toe to the wall was recorded to the nearest 0.1 cm[8,64,123]. The reliability and validity of this test has been previously established[8,64,123].

XII.III.III DATA ANALYSIS

Measurements were recorded on independent data collection sheets for examiner. This data was then collaborated into an Excel spreadsheet (Microsoft Corporation, Redmond, USA).

XII.III.IV STATISTICAL ANALYSES

Data were analysed using Statistica software (StatSoft, Inc. 2004. STATISTICA, Data Analysis Software System, Version 11. www.statsoft.com). Correlations between data were determined using Cronbach's α, where a perfect α = 1. Intra-rater reliability was accepted as α ≥ 0.7. All data are presented as the mean ± SD.

XII.III.V RESULTS

The results for each parameter tested are shown in the tables which follow.

Table XII.I: *The intra-reliability of the examiner for anthropometric measurements of participants in the reliability study (n = 6).*

Variable	Day	Mean ± SD	Cronbach's α
Anthropometric measurements sum of 7 skinfolds	**1**	66.7 ± 12.7	1.0
	2	67.8 ± 11.5	1.0
	3	67.5 ± 12.7	1.0

**Cronbach's α ≥ 0.7 indicates satisfactory intra-rater reliability.*

Table XII.II: *The reliability of the foot posture index score for participants in the reliability study (n = 6).*

Variable	Day	Mean ± SD			Cronbach's α		
		Left	Right	Average	Left	Right	Average
Foot posture index test	**1**	3.7 ± 3.3	5.5 ± 4.4	4.6 ± 3.7	0.96	0.98	0.98
	2	4.8 ± 3.5	6.0 ± 4.7	5.4 ± 4.0	0.96	0.91	0.95
	3	3.8 ± 2.8	5.0 ± 4.2	4.4 ± 3.5	0.92	0.92	0.98

**Cronbach's α ≥ 0.7 indicates satisfactory intra-rater reliability.*

Table XII.III: *The intra-reliability of the examiner for hamstring muscle flexibility of participants in the reliability study (n = 6).*

Variable	Day	Mean ± SD			Cronbach's α		
		Left	Right	Average	Left	Right	Average
Muscle flexibility hamstrings (°) Active knee extension test (popliteal angle)	**1**	147.2 ± 8.1	147.9 ± 10.9	147.6 ± 9.4	0.96	0.99	0.98
	2	147.0 ± 10.6	148.2 ± 8.2	148.1 ± 9.3	0.89	0.94	0.93
	3	149.9 ± 11.1	149.1 ± 9.0	149.5 ± 10.0	0.96	0.94	0.96

**Cronbach's α ≥ 0.7 indicates satisfactory intra-rater reliability.*

Table XV.IV: *The intra-reliability of the examiner for hallux dorsiflexion ROM of participants in the reliability study (n = 6).*

Variable	Day	Mean ± SD			Cronbach's α		
		Left	Right	Average	Left	Right	Average
Range of motion (°) Hallux dorsiflexion	**1**	81.4 ± 12.9	78.8 ± 13.1	80.1 ± 12.8	0.94	0.96	0.97
	2	83.3 ± 10.1	80.4 ± 11.1	81.9 ± 10.5	0.92	0.94	0.97
	3	84.0 ± 10.1	81.7 ± 9.6	82.8 ± 9.5	0.99	0.99	1.0

**Cronbach's α ≥ 0.7 indicates satisfactory intra-rater reliability.*

Table XII.V: *The intra-reliability of the examiner for hallux plantarflexion ROM of participants in the reliability study (n = 6).*

Variable	**Day**	**Mean ± SD**			**Cronbach's α**		
		Left	**Right**	**Average**	**Left**	**Right**	**Average**
Range of motion (°) Hallux plantarflexion	**1**	44.5 ± 12.3	46.1 ± 13.5	45.6 ± 12.1	0.97	0.91	0.99
	2	44.9 ± 10.9	47.4 ± 12.7	46.1 ± 11.3	0.90	0.88	0.98
	3	46.9 ± 10.3	49.3 ± 11.1	48.1 ± 10.4	0.99	0.98	0.99

**Cronbach's α ≥ 0.7 indicates satisfactory intra-rater reliability.*

Table XVII.VI: *The intra-reliability of the examiner for calf muscle flexibility of participants in the reliability study (n = 6).*

Variable	**Day**	**Mean ± SD**			**Cronbach's α**		
		Left	**Right**	**Average**	**Left**	**Right**	**Average**
Muscle flexibility calf (cm) Ankle lunge test	**1**	9.7 ± 4.1	9.7 ± 4.8	9.7 ± 4.4	1.0	1.0	1.0
	2	9.8 ± 4.1	9.9 ± 4.7	9.8 ± 4.4	0.98	1.0	1.0
	3	9.7 ± 4.4	9.7 ± 4.6	9.7 ± 4.5	0.9	1.0	1.0

**Cronbach's α ≥ 0.7 indicates satisfactory intra-rater reliability.*

XII.IV SUMMARY AND CONCLUSION

Intra-rater reliability is expressed as Cronbach's α, where a perfect score is equal to one. Acceptable intra-rater reliability is regarded as Cronbach's α ≥ 0.7. Therefore the results of the intra-rater reliability tested for each of the parameters required for the purposes of this study, show satisfactory reliability[102].

APPENDIX XIII

Ethical Approval

UNIVERSITY OF CAPE TOWN

Health Sciences Faculty
Human Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
e-mail: shuretta.thomas@uct.ac.za

15 June 2012

HREC REF: 258/2012

Ms C Marshall
c/o Dr T Burgess
Physiotherapy
Health & Rehab
F-Floor
OMB

Dear Ms Marshall

PROJECT TITLE: MINIMALIST VERSUS CONVENTIONAL RUNNING SHOES. EFFECTS ON LOWER LIMB INJURY PREVALENCE AND MUSCLE FUNCTION IN EXPERIENCED DISTANCE RUNNERS

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

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year till the 30th June 2013

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/research/humanethics/forms)

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

Please quote the HREC. REF in all your correspondence.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS
Federal Wide Assurance Number: FWA00001637.

Institutional Review Board (IRB) number: IRB00001938
This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP) and Declaration of Helsinki guidelines.

s.thomas HREC Ref 258/2012 – 15 June 2012

APPENDIX XIV

Correlational Results

XIV.I Significant Correlational Analyses

Table XIV.I shows the significant correlational analyses that were investigated in this study. Due to the small sample size and lack of power in this study, it is difficult to correctly interpret the results of these correlational analyses.

Table XIV.I: *Summary of significant correlational analyses observed in this study.*

Relationships	Total group	Experimental group	Control group
General satisfaction with comfort and support of shoes and satisfaction with continuing to run in conventional/ minimalist shoes scores	*Significant*	*Significant*	Non-significant
Weekly duration of running and general satisfaction with training and performance	*Significant*	Non-significant	Non-significant
Total satisfaction scores and weekly duration of running	*Significant*	Non-significant	Non-significant
Total satisfaction scores and hallux plantarflexion ROM	Non-significant	Non-significant	*Significant*
Total satisfaction scores and hallux dorsiflexion ROM	Non-significant	*Significant*	Non-significant

XIV.I.I Relationship between General Satisfaction with Comfort and Support of Shoes and Satisfaction with Continuing to Run in Conventional/Minimalist Shoes Scores

There were significant positive correlations between the differences of week 12 to week zero measurements in general satisfaction with comfort and support of shoes and satisfaction with continuing to run in conventional/minimalist shoes scores for the total group (r = 0.54; p = 0.003) and the experimental group (r = 0.72; p = 0.004). No significant correlations were found between differences of week 12 to week zero measures in general satisfaction with comfort and support of shoes and satisfaction with continuing to run in conventional/minimalist shoes scores for the control group (r = 0.06; p = 0.84).

In summary a negative correlation indicates that as satisfaction with continuing to run in conventional/ minimalist shoes scores decreases, general satisfaction with comfort and support of shoes improves. A positive correlation indicates that as satisfaction with continuing to run in conventional/minimalist shoes scores decreases, general satisfaction with comfort and support of shoes deteriorates. A summary of relationships between general satisfaction with comfort and support of shoes and satisfaction with continuing to run in conventional/ minimalist shoes scores is provided in Table XIV.II.

Table XIV.II: *Relationships between general satisfaction with comfort and support of shoes and satisfaction with continuing to run in conventional/minimalist shoes scores. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Total group			**Experimental group**			**Control group**		
Relationship	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
+	0.54	***0.003***	+	0.72	***0.004***	+	0.06	0.84

Note: A negative correlation (-) indicates that as general satisfaction with comfort and support of shoes scores improves, satisfaction with continuing to run in conventional/minimalist shoes scores decreases. A positive correlation (+) indicates that as general satisfaction with comfort and support of shoes scores decrease, satisfaction with continuing to run in convention/ minimalist shoes scores also deteriorates.

XIV.I.II Relationship between Weekly Duration of Running and General Satisfaction with Training and Performance

There was a significant positive correlation between the differences of week 12 to week zero measures in weekly duration of running and general satisfaction with training and performance for the total group (r = 0.39; p = 0.04). No significant correlations were found between differences of week 12 to week zero measures in weekly duration of running and general satisfaction with training and performance for the experimental group (r = 0.24; p = 0.4) or control group (r = 0.5; p = 0.07).

In summary a negative correlation indicates that as general satisfaction with training and performance decreases, weekly duration of running improves. A positive correlation indicates that as general satisfaction with training and performance decreases, weekly duration of running deteriorates. A summary of relationships between weekly duration of running and general satisfaction with training and performance is provided in Table XIV.III.

Table XIV.III: *Relationship between weekly duration of running and general satisfaction with training and performance. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Total group			**Experimental group**			**Control group**		
Relationship	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
+	0.39	***0.04***	+	0.24	0.4	+	0.5	0.07

Note: A negative correlation (-) indicates that as general satisfaction with training and performance decreases, weekly duration of running improves. A positive correlation (+) indicates that as general satisfaction with training and performance decreases, weekly duration of running deteriorates.

XIV.I.III Relationship between Total Satisfaction Scores and Weekly Duration of Running

There was a significant positive correlation between the differences of week 12 to week zero measures in total satisfaction scores and weekly duration of running for the total group (r = 0.42; p = 0.03). No significant correlations were found between differences of week 12 to week zero measures in total satisfaction scores and weekly duration of running for the experimental group (r = 0.34; p = 0.24) or control group (r = 0.51; p = 0.06).

In summary a negative correlation indicates that as total satisfaction score decreases, weekly duration of running improves. A positive correlation indicates that as total satisfaction score decreases, weekly duration of running deteriorates. A summary of relationships between total satisfaction score and weekly duration of running is provided in Table XIV.IV.

Table XIV.IV: *Relationship between weekly duration of running and total satisfaction scores. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Total group			Experimental group			Control group		
Relationship	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
+	0.42	***0.03***	+	0.34	0.24	+	0.51	0.06

Note: A negative correlation (-) indicates that as total satisfaction scores decreases, weekly duration of running improves. A positive correlation (+) indicates that as total satisfaction scores decreases, weekly duration of running deteriorates.

XIV.I.IV Relationship between Total Satisfaction Scores and Hallux Plantarflexion ROM

There was a significant positive correlation between the differences of week 12 to week zero measures in total satisfaction scores and hallux plantarflexion ROM for the control group (r = 0.61; p = 0.02). No significant correlations were found between differences of week 12 to week zero measures in total satisfaction score and hallux plantarflexion ROM for the total group (r = 0.21; p = 0.29) or experimental group (r = -0.12; p = 0.59).

In summary a negative correlation indicates that as total satisfaction scores decreases, hallux plantarflexion ROM improves. A positive correlation indicates that as total satisfaction scores decreases, hallux plantarflexion ROM deteriorates. A summary of relationships between total satisfaction score and hallux plantarflexion ROM is provided in Table XIV.V.

Table XIV.V: *Relationship between total satisfaction scores and hallux plantarflexion ROM. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Total group			Experimental group			Control group		
Relationship	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
+	0.21	0.29	-	0.12	0.59	+	0.61	***0.02***

Note: A negative correlation (-) indicates that as total satisfaction scores decreases, hallux plantarflexion ROM improves. A positive correlation (+) indicates that as total satisfaction scores decreases, hallux plantarflexion ROM deteriorates.

XIV.I.V Relationship between Total Satisfaction Scores and Hallux Dorsiflexion ROM

There was a significant positive correlation between the differences of week 12 to week zero measures in total satisfaction scores and hallux dorsiflexion ROM for the experimental group (r = 0.59; p = 0.03). No significant correlations were found between differences of week 12 to week zero measures in total satisfaction score and hallux dorsiflexion ROM for the total group (r = 0.31; p = 0.11) or control group (r = -0.08; p = 0.79).

In summary a negative correlation indicates that as total satisfaction scores decreases, hallux dorsiflexion ROM improves. A positive correlation indicates that as total satisfaction scores decreases, hallux dorsiflexion ROM deteriorates. A summary of relationships between total satisfaction scores and hallux dorsiflexion ROM is provided in Table XIV.VI.

Table XIV.VI: *Relationship between total satisfaction scores and hallux dorsiflexion ROM. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Total group			Experimental group			Control group		
Relationship	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
+	0.31	0.11	+	0.59	***0.03***	-	0.08	0.79

Note: A negative correlation (-) indicates that as total satisfaction scores decrease, hallux dorsiflexion ROM improves. A positive correlation (+) indicates that as total satisfaction scores decreases, hallux dorsiflexion ROM deteriorates.

XIV.II Non-Significant Correlational Analyses

XIV.II.I Relationship between General Satisfaction with Comfort and Support of Shoes and Pain Severity Scores

There were no significant correlations between the differences of week 12 to week zero measures in general satisfaction with comfort and support of shoes and pain severity scores for the total group (r = 0.08; p = 0.69), experimental group (r = 0.17; p = 0.56) or control groups (r = 0.13; p = 0.65) (Table XIV.VII)

XIV.II.II Relationship between General Satisfaction with Lower Limb Function and Hamstring Muscle Flexibility

There were no significant correlations between the differences of week 12 to week zero measures in general satisfaction with lower limb function and hamstring muscle flexibility for the total group (r = -0.16; p = 0.46), experimental group (r = 0.10; p = 0.73) or control groups (r = -0.41; p = 0.15) (Table XIV.VII).

XIV.II.III Relationship between General Satisfaction with Lower Limb Function and Calf Muscle Flexibility

There were no significant correlations between the differences of week 12 to week zero measures in general satisfaction with lower limb function and calf muscle flexibility for the total group (r = -0.22; p = 0.26), experimental group (r = 0.10; p = 0.76) or control groups (r = -0.34; p = 0.24) (Table XIV.VII).

XIV.II.IV Relationship between General Satisfaction with Lower Limb Function and Lower Limb Muscle Power

There were no significant correlations between the differences of week 12 to week zero measures in general satisfaction with lower limb function and lower limb muscle power for the total group (r = 0.18; p = 0.37), experimental group (r = 0.43; p = 0.13) or control groups (r = 0.03; p = 0.91) (Table XIV.VII).

XIV.II.V Relationship between Weekly Running Distance and General Satisfaction with Training and Performance

There were no significant correlations between the differences of week 12 to week zero measures in weekly running distance and general satisfaction with training and performance for the total group (r = 0.36; p = 0.06), experimental group (r = 0.13; p = 0.66) or control groups (r = 0.48; p = 0.08) (Table XIV.VIII).

XIV.II.VI Relationship between General Satisfaction with Lower Limb Function and General Satisfaction with Training and Performance

There were no significant correlations between the differences of week 12 to week zero measures in general satisfaction with lower limb function and general satisfaction with training and performance for the total group (r = -0.10; p = 0.60), experimental group (r = -0.18; p = 0.53) or control groups (r = 0.15; p = 0.61) (Table XIV.IX).

XIV.II.VII Relationship between Overall Satisfaction with the Type of Running Shoe and Weekly Running Distance

There were no significant correlations between the differences of week 12 to week zero measures in overall satisfaction with the type of running shoes and weekly running distance for the total group (r = 0.31; p = 0.11), experimental group (r = 0.38; p = 0.18) or control groups (r = 0.46; p = 0.1) (Table XIV.IX).

XIV.II.VIII Relationship between Total Satisfaction Scores and Weekly Running Distance

There were no significant correlations between the differences of week 12 to week zero measures in total satisfaction scores and weekly running distance for the total group (r = 0.38; p = 0.05), experimental group (r = 0.28; p = 0.33) or control groups (r = 0.48; p = 0.09) (Table XIV.X).

XIV.II.IX Relationship between Total Satisfaction Scores and Calf Endurance

There were no significant correlations between the differences of week 12 to week zero measures in total satisfaction scores and calf endurance for the total group (r = 0.007; p = 0.97), experimental group (r = 0.09; p = 0.75) or control groups (r = -0.2; p = 0.5) (Table XIV.X).

IV.II.X Relationship between Total Satisfaction Scores and Lower Limb Muscle Power

There were no significant correlations between the differences of week 12 to week zero measures in total satisfaction scores and lower limb muscle power for the total group (r = 0.05; p = 0.81), experimental group (r = -0.02; p = 0.96) or control groups (r = 0.14; p = 0.64) (Table XIV.X).

Table XIV.VII: *Relationships between general satisfaction with comfort and support of shoes and pain severity scores as well as general satisfaction with lower limb function and hamstring muscle flexibility, calf muscle flexibility and lower limb muscle power. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Correlation	**Total group**			**Experimental group**			**Control group**		
General satisfaction with comfort and support of shoes* and *pain severity scores	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
	+	0.08	0.69	+	0.17	0.56	+	0.13	0.65
General satisfaction with lower limb function* and *hamstring muscle flexibility									
	-	0.16	0.46	+	0.10	0.73	-	0.41	0.15
General satisfaction with lower limb function* and *calf muscle flexibility									
	-	0.22	0.26	+	0.01	0.76	-	0.34	0.24
General satisfaction with lower limb function* and *lower limb muscle power									
	+	0.18	0.37	+	0.43	0.13	+	0.03	0.91

Note: A negative correlation (-) indicates that as general satisfaction with comfort and support of shoes decreases, pain severity score increase. In addition as hamstring muscle flexibility, calf muscle flexibility and lower limb muscle power decreases, general satisfaction with lower limb function improves. A positive correlation (+) indicates that as general satisfaction with comfort and support of shoes decreases, pain severity scores decrease. In addition as hamstring muscle flexibility, calf muscle flexibility and lower limb muscle power decreases, general satisfaction with lower limb function deteriorates.

Table XIV.VIII: *Relationship between weekly running distance and general satisfaction with training and performance. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Correlation	Total group			Experimental group			Control group		
Weekly running distance* and *general satisfaction with training and performance	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
	+	0.36	0.06	+	0.13	0.66	+	0.48	0.08

Note: A negative correlation (-) indicates that as general satisfaction with training and performance decreases, weekly running distance improves. A positive correlation (+) indicates that as general satisfaction with training and performance decreases, weekly running distance deteriorates.

Table XIV.IX: *Relationships between general satisfaction with lower limb function and general satisfaction with training and performance as well as overall satisfaction with the type of running shoes and weekly running distance. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Correlation	**Total group**			**Experimental group**			**Control group**		
General satisfaction with lower limb function* and *general satisfaction with training and performance	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
	-	0.10	0.60	-	0.18	0.53	+	0.15	0.61
Overall satisfaction with the type of running shoes and weekly running distance									
	+	0.31	0.11	+	0.38	0.18	+	0.46	0.1

Note: A negative correlation (-) indicates that as general satisfaction with training and performance decreases, general satisfaction with lower limb function improves. In addition, as overall satisfaction with the type of running shoes decreases, weekly running distance increases. A positive correlation (+) indicates that as general satisfaction with training and performance decreases, general satisfaction with training and performance deteriorates. In addition, as overall satisfaction with the type of running shoes decreases, weekly running distance deteriorates.

Table XIV.X: *Relationships between total satisfaction scores and weekly running distance, calf endurance and lower limb muscle power. Note '+' indicates a positive correlation, and '-' indicates a negative correlation.*

Correlation	**Total group**			**Experimental group**			**Control group**		
Total satisfaction scores and weekly running distance	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**	**Relationship**	**r**	**p**
	+	0.38	0.05	+	0.28	0.33	+	0.48	0.09
Total satisfaction scores and calf endurance									
	+	0.007	0.97	+	0.09	0.75	-	0.2	0.5
Total satisfaction scores and lower limb muscle power									
	+	0.05	0.81	-	0.02	0.96	+	0.14	0.64

Note: A negative correlation (-) indicates that as total satisfactions scores decreases weekly running distance, calf endurance and lower limb muscle power, improves. In addition, as overall satisfaction with the type of running shoes decreases, weekly running distance increases. A positive correlation (+) indicates that as total satisfaction scores decreases, weekly running distance, calf endurance and lower limb muscle power deteriorates.

APPENDIX XV

Results Tables

Table XV.I: *Calf endurance of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental			Control		
	Left$^{\alpha}$	Right	Average	Left$^{\alpha}$	Right	Average
0	25.0 ± 5.7	26.5 ± 4.9	25.7 ± 5.1	24.6 ± 4.7	24.9 ± 5.5	24.8 ± 4.8
4	26.0 ± 6.6	27.5 ± 7.3	26.7 ± 6.9	26.6 ± 4.2	26.6 ± 4.8	26.6 ± 4.3
8	27.7 ± 7.7*	28.3 ± 7.6	28.0 ± 7.4	26.4 ± 5.2*	26.8 ± 4.7	26.6 ± 4.9
12	28.5 ± 7.6**	29.4 ± 8.6	28.9 ± 8.0	27.1 ± 4.3**	26.9 ± 3.7	27.0 ± 3.9

Significant differences:

α main effect of time (p = 0.004)

*week 8 versus week 0 (p = 0.043)

**week 12 versus week 0 (p = 0.003)

Table XV.II: *Lower limb muscle power (cm) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	42.2 ± 8.1	40.7 ± 7.5
4	44.0 ± 7.5	41.9 ± 7.6
8	44.1 ± 7.0	42.4 ± 6.5
12	44.5 ± 8.2	43.6 ± 6.5

Table XV.III: *Hallux plantarflexion ROM (°) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental			Control		
	Left$^{\alpha}$	Right$^{\alpha\alpha}$	Average	Left$^{\alpha}$	Right$^{\alpha\alpha}$	Average
0	44.9 ± 10.7	43.5 ± 10.8	44.2 ± 9.5	40.1 ± 16.2	41.2 ± 13.4	40.6 ± 14.0
4	43.6 ± 8.8	45.0 ± 9.9	44.3 ± 8.4	39.2 ± 16.5	42.5 ± 12.5	40.8 ± 14.1
8	45.9 ± 8.5*	47.9 ± 8.2**	46.9 ± 8.1	41.1 ± 15.2*	46.3 ± 12.6**	43.7 ± 13.5
12	47.2 ± 9.4**	48.1 ± 8.0**	47.7 ± 8.6	43.2 ± 15.9**	46.3 ±12.9**	44.7 ± 14.1

Significant differences:

α main effect of time (p = 0.00002)

**week 12 versus week 0 (p = 0.005)

*week 8 versus week 4 (p = 0.024)

**week 12 versus week 4 (p = 0.0002)

αα main effect of time (p = 0.00001)

**week 8 versus week 0 (p = 0.0002)

**week 12 versus week 0 (p = 0.0002)

*week 8 versus week 4 (p = 0.014)

*week 12 versus week 4 (p = 0.01)

Table XV.IV: *Hallux dorsiflexion ROM (°) of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental			Control		
	Left$^{\alpha}$	Right$^{\alpha\alpha}$	Average	Left$^{\alpha}$	Right$^{\alpha\alpha}$	Average
0	81.3 ± 11.4	81.7 ± 11.1	81.5 ± 11.0	88.8 ± 8.4	87.8 ± 9.8	88.3 ± 8.5
4	82.3 ± 9.5**	85.4 ± 9.4	83.9 ± 9.3	92.0 ± 8.3**	87.4 ± 11.5	89.7 ± 9.3
8	87.0 ± 9.8**	83.8 ± 8.7	85.4 ± 9.0	93.4 ± 6.7**	89.3 ± 10.3	91.4 ± 8.1
12	87.4 ± 10.0**	85.4 ± 8.8**	86.4 ± 9.2	94.3 ± 5.7**	90.3 ± 9.4**	92.3 ± 7.2

Significant differences:

α main effect of time (p = 0.0000)

**week 4 versus week 0 (p = 0.0002)

**week 8 versus week 0 (p = 0.0001)

**week 12 versus week 0 (p = 0.0001)

αα main effect of time (p = 0.001)

**week 12 versus week 0 (p = 0.003)

**week 12 versus week 4 (p = 0.002)

Table XV.V: *General satisfaction with lower limb function of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	6.5 ± 1.5	6.9 ± 1.5
4	7.0 ± 1.5	7.6 ± 1.3
8	7.3 ± 1.4	7.1 ± 1.3
12	7.9 ± 0.8	7.0 ± 1.6

Table XV.VI: *General satisfaction with comfort and support of shoes of participants in the experimental (n = 15) and control (n = 14) groups. Tests were conducted at 0, 4, 8 and 12 weeks. Data are expressed as mean ± SD.*

Week	Experimental	Control
0	15.5 ± 0.8	15.6 ± 1.7
4	12.5 ± 3.7	15.6 ± 1.5
8	13.9 ± 3.1	16.00 ± 1.2
12	14.3 ± 3.6	15.7 ± 2.3

APPENDIX XVI

Recruitment Advertisement

EXPERIENCED MALE DISTANCE RUNNERS WANTED FOR UCT RESEARCH

For a study investigating: Minimalist versus conventional running shoes: The effects of lower limb injury incidence, pain and muscle function in experienced distance runners

Study outline

I am a Masters student at UCT, investigating the difference between running in conventional and minimalist running shoes on lower limb injury and muscle performance. The study aims to provide information regarding potential running injury prevention and a safer participation in sport. It also aims to further enrich knowledge with regards to the purchasing of running shoes.

The study requires participants to complete an injury report form and a satisfaction questionnaire along with physical testing. These tests will measure: calf endurance; muscle flexibility; muscle power; foot posture index; and hallux range of motion. Testing will run over a consecutive 12 week period with testing every 4 weeks. It will be requested of you to keep a detailed training log with regards to injury, training history, pain scores and exertion of training sessions, over the testing period.

Those interested in participating should:

- Be between the ages of 18 and 50 years
- Run between 40-60km/week in the last 6 months
- Have been running for 2 years or more

Benefits of participating in the study include

- Individual anthropometric measurements (Height, weight, BMI, body fat %)
- A pair of minimalist running shoes along with a 4 week training programme
- Feedback regarding the results of the study

DEADLINE FOR APPLICATIONS: 30 August 2012

If you are interested in taking part in the study and would like additional information, please contact:

- **Charlene Marshall**
- **0731776330**
- **Email:** charleneclairemarshall@gmail.com

APPENDIX XVII

Participant Feedback Information Sheets

UCT RESEARCH FOR MSc PHYSIOTHERAPY

PARTICIPANT FEEDBACK

Minimalist versus conventional running shoes: Effects on lower limb injury prevalence, pain and muscle function in experienced distance runners

December 2012

Dear

Thank you very much for participating in this study. We realise that the testing procedure was both time-consuming and strenuous, and cannot adequately express our gratitude to you for completing the study. We really appreciated your continued good humour and patience throughout the testing procedure.

We also hope that you enjoyed the testing experience, and thank you for excellent results that you gave us. We trust that you will find the information contained in this folder both interesting and exciting.

Should you require any further details regarding the results of the study, please do not hesitate to contact Charlene at 0731776330 or charleneclairemarshall@gmail.com.

Thank you once again for completing the study!

Wishing you good running,

Best regards,

Charlene Marshall

Personal Information

Body mass:

Stature:

Body fat percentage:

Sum of seven skinfolds:

Lean body mass:

BMI:

ANTHROPOMETRY

Anthropometry is the process of measuring physical dimensions of the human body. These measurements are then used to either describe size and proportions, or to indirectly estimate body composition.

In this study, body mass, stature and skinfold thicknesses were recorded. From these measurements, the sum of seven skinfolds, estimated body fat (%) and lean body mass were recorded.

1. Body Fat Percentage

The Durnin and Wormersley technique is used to estimate body fat percentage. The calculation involves measuring four skinfold sites, being: triceps; biceps; subscapular; and suprailiac, and substituting the log of their sum into an equation.

The body fat percentage of a person is the total weight of fat divided by total weight. Body fat includes essential body fat and storage body fat. This calculation is a measure of fitness level, since it is the only body measurement which directly calculates a person's relative body composition without regard to height or weight. Although it may not give an accurate reading of real body fat percentage, it is a reliable measure of body composition change over a period of time, provided the test is carried out by the same person with the same technique.

Description	Women	Men
Essential fat*	10-13%	2-5%
Athletes	14-20%	6-13%
Fitness	21-24%	14-17%
Average	25-31%	18-24%
Obese	32%+	25%+

*Essential fat is the level below which physical and physiological health would be negatively affected.

2. Sum of Seven Skinfolds

Body fat may be described as the sum of seven skinfolds. The seven sites used are triceps, biceps, subscapular, suprailiac, calf, thigh and abdomen.

There is a tendency in laboratories around the world to move away from expressing an athlete's body fat as a percentage, but rather to express body fat as a sum of seven skinfolds (mm). This is because the use of skinfold thicknesses to predict body fat percentage has inherent inaccuracies. It is also assumed that the densities of the fat and fat-free mass are constant. However, these assumptions are not always met. It is therefore recommended that the sum of seven skinfolds be used to assess body composition.

3. Lean Body Mass

Lean body mass (or fat-free mass) is calculated as:

lean body mass = (body mass) - (fat mass)

where fat mass = body mass x % body fat

4. Body Mass Index (BMI)

BMI= mass (kg)/(height(m))^2

The BMI provides a measure that allows the comparison of the adiposity of individuals of different heights and weights. While BMI largely increases as adiposity increases, due to differences in body composition it is not necessarily an accurate indicator of body fat. For example, individuals with greater muscle mass will have higher BMIs. The thresholds between 'normal' and 'overweight' and between 'overweight' and 'obese' are sometimes disputed for this reason. The duality of the BMI is that, whilst easy-to-use as a general calculation, it is limited in how accurate and pertinent the data obtained from it can be. As the BMI formula depends only upon weight and height, its assumptions about the distribution between lean mass and adipose tissue are inexact.

Category	**BMI range (kg.m^{-2})**
Very severely underweight	Less than 15.0
Severely underweight	From 15.0-15.9
Underweight	From 16.0-18.4
Normal (healthy weight)	From 18.5-24.9
Overweight	From 25-29.9
Obese class I (Moderately obese)	From 30-34.5
Obese class II (Severely obese)	From 35-40
Obese class III (Very severely obese)	Over 40

APPENDIX XVIII

Internal Consistency of the Satisfaction Questionnaire Items

Week 0

Table XVIII.I: *Item-Total Statistics*

	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha if item deleted
0 Weeks: Running shoe satisfaction	39.79	14.813	.013	.631
0 Weeks: Current training status in terms of frequency	40.14	11.766	.427	.545
0 Weeks: Current training status in terms of intensity	40.31	11.436	.541	.517
0 Weeks: Current training status in terms of duration	40.31	11.793	.473	.535
0 Weeks: Current performance level (time and distance)	40.31	11.079	.573	.505
0 Weeks: Satisfaction of lower limb flexibility	40.66	13.663	.131	.619
0 Weeks: Satisfaction of lower limb muscle strength	40.24	14.047	.144	.609
0 Weeks: Satisfaction of lower limb comfort	40.10	13.382	.287	.581
0 Weeks: Satisfaction of foot comfort	39.90	13.667	.341	.576
0 Weeks: Satisfaction of support from running shoes	39.79	14.170	.377	.582
0 Weeks: Satisfaction of cushioning from running shoes	39.86	15.266	-.039	.629
0 Weeks: Feel about continuing in conventional/minimalist shoes	40.31	15.579	-.123	.652

Week 4

Table XVIII.II: *Item-Total Statistics*

	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha if item deleted
4 Weeks: Running shoe satisfaction	38.45	41.113	.645	.873
4 Weeks: Current training status in terms of frequency	38.86	41.409	.499	.881
4 Weeks: Current training status in terms of intensity	38.72	44.207	.347	.887
4 Weeks: Current training status in terms of duration	39.00	41.429	.507	.880
4 Weeks: Current performance level (time and distance)	39.17	40.933	.530	.879
4 Weeks: Satisfaction of lower limb flexibility	38.72	42.778	.465	.882
4 Weeks: Satisfaction of lower limb muscle strength	38.66	42.377	.482	.881
4 Weeks: Satisfaction of lower limb comfort	38.83	39.648	.701	.869
4 Weeks: Satisfaction of foot comfort	38.79	37.527	.761	.864
4 Weeks: Satisfaction of support from running shoes	38.90	39.882	.720	.868
4 Weeks: Satisfaction of cushioning from running shoes	38.86	38.909	.735	.866
4 Weeks: Feel about continuing in conventional/minimalist shoes	38.83	39.791	.618	.874

Week 8

Table XVIII.III: *Item-Total Statistics*

	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha if item deleted
8 Weeks: Running shoe satisfaction	39.57	35.810	.550	.824
8 Weeks: Current training status in terms of frequency	40.00	32.815	.581	.820
8 Weeks: Current training status in terms of intensity	40.07	33.254	.539	.824
8 Weeks: Current training status in terms of duration	40.11	31.062	.687	.809
8 Weeks: Current performance level (time and distance)	40.32	31.337	.712	.807
8 Weeks: Satisfaction of lower limb flexibility	40.07	35.698	.466	.829
8 Weeks: Satisfaction of lower limb muscle strength	39.89	38.321	.277	.840
8 Weeks: Satisfaction of lower limb comfort	39.89	38.247	.323	.837
8 Weeks: Satisfaction of foot comfort	39.75	36.046	.518	.826
8 Weeks: Satisfaction of support from running shoes	39.79	36.026	.435	.831
8 Weeks: Satisfaction of cushioning from running shoes	39.93	35.254	.461	.829
8 Weeks: Feel about continuing in conventional/minimalist shoes	39.89	36.321	.413	.832

Week 12

Table XVIII.IV: *Item-Total Statistics*

	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha if Item deleted
12 Weeks: Running shoe satisfaction	35.64	38.090	.519	.851
12 Weeks: Current training status in terms of frequency	36.21	37.656	.568	.847
12 Weeks: Current training status in terms of intensity	36.00	35.630	.668	.839
12 Weeks: Current training status in terms of duration	36.18	35.930	.717	.835
12 Weeks: Current performance level (time and distance)	36.29	34.952	.769	.830
12 Weeks: Satisfaction of lower limb flexibility	35.75	43.528	.173	.870
12 Weeks: Satisfaction of lower limb muscle strength	35.71	42.952	.218	.868
12 Weeks: Satisfaction of lower limb comfort	35.61	39.803	.555	.849
12 Weeks: Satisfaction of foot comfort	35.61	35.210	.756	.831
12 Weeks: Satisfaction of support from running shoes	35.86	38.275	.521	.851
12 Weeks: Satisfaction of cushioning from running shoes	35.79	38.915	.525	.850