ANATOMICAL ALIGNMENT AND MUSCLE STRENGTH AS PREDICTORS OF OVERUSE INJURIES IN LONG-DISTANCE ATHLETES

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I know that, with these words, I will be repeating the thoughts and "thank-you's" of many students upon completion of postgraduate studies, but I will go ahead anyway:

"Through many dangers, toils and snares,
I have already come;
'tis grace hath brought me safe thus far,
and grace will lead me home."

- John Newton ("Amazing grace")

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ABSTRACT

Background

Running is a popular choice of physical activity for many people because it is relatively inexpensive and not bound to a high-tech facility (Mann *et al.*, 1981:190). Associated with the increased popularity of running is an increase in the incidence of running-related injuries (Mann et al., 1981:190; Wen et al., 1997:1291). This ranges from as little as 11 percent (Montgomery et al., 1989:239) to as high as 75 percent (Van Mechelen, 1995:161) depending on which study is cited.

In a study by Marti et al. (1988:289), one in five runners were forced to fully interrupt training due to injuries. One in seven sought medical attention, and one in forty were forced to miss work. A clear set of predictor variables that can be used to identify the high risk runner and initiate preventative measures, would therefore be of great value to medical practitioners (Frederickson, 1996:50; O'Toole, 1992:S360).

A variety of factors have been identified as role players in the aetiology of running injuries (Krivickas, 1997:133; Layman & Morris, 1991:33; Montgomery et al., 1989:237; Pinshaw et al., 1984:291; Wen et al., 1997:1292). These factors can be described as being either intrinsic or extrinsic in nature (Gellman & Burns, 1996:263. Intrinsic factors refer to inherent characteristics of the runner e.g. anatomical alignment and joint range of motion (Krivickas, 1997:135) as well as muscle strength characteristics (O'Toole, 1992:S360) and psychological factors (Layman & Morris, 1991:28; Robbins & Joseph, 1985:23). Training errors, faulty equipment and training surfaces on the other hand are external to the athlete and classified as extrinsic risk factors (Krivickas, 1997:133).

The relationship of anatomical alignment measures and overuse injuries in runners is not yet well established, and the results of existing studies are often contradictory

(Krivickas, 1997:133). Inadequate strength and muscular imbalances are also cited to be important risk factors in the aetiology of running-related injuries (Jönhagen et al., 1994:226; Kibler et al., 1991:68; O'Toole, 1992:S360).

OBJECTIVES

The purpose of this study was to retrospectively examine the importance of anatomical alignment measures in predicting the risk of overuse injuries in runners. The relationship between muscle-strength characteristics and running injuries was also investigated.

METHODS

Fifty-two runners were recruited from marathon clubs in the Potchefstroom-Klerksdorp area. The respondents were subjected to a battery of tests that included a questionnaire, a standard pre-season medical examination, and measuring of anatomical alignment, anthropometric parameters and muscle-strength.

Subjects were required to complete a questionnaire pertaining to their training parameters and demographic information. Running-related injuries were diagnosed and recorded during the standard pre-season physical examination. The anatomical alignment measures included forefoot varus, longitudinal arch angle, arch index, leg-length discrepancy, knee varus/ valgus, Q-angle, dynamic hip abductor strength (Trendelenberg test), posterior thigh and lower-back flexibility (sit-and-reach), and hip extension range of motion.

Muscle strength was measured for both the knee and ankle joint, concentrically as well as eccentrically. From these results it was possible to calculate the conventional and functional strength ratios for knee flexion and extension, and for ankle plantar and dorsiflexion. These values were then compared between injured and uninjured subjects.

RESULTS

Accurate sets of predictor variables were identified for male and female subjects respectively. The variables that could predict injured male runners with 94 % accuracy were: forefoot varus, arch index, posterior thigh and lower back flexibility and the percentage body fat. Predictor variables for female subjects included forefoot varus, arch index, longitudinal arch angle, knee varus/ valgus, Q-angle, functional leg-length discrepancy, hip extension range of motion and running experience. These variables were 88 % accurate in predicting injured female subjects.

Muscle-strength characteristics were not found to be related to the incidence of running injuries in the present study.

CONCLUSIONS

It is concluded that anatomical alignment measures did play a significant role in the aetiology of running injuries and could be used accurately to injured and uninjured subjects. Interestingly, the only variables that were included in both the male and female models were forefoot varus and arch index.

No differences were found in the muscle-strength characteristics of injured and uninjured subjects and subsequently no relationship could be discerned between the above mentioned variables. It appears that muscle strength may not be as important as anatomical alignment in the development of injuries in runners.

KEYWORDS

running injuries, runners, anatomical alignment, muscle strength

OPSOMMING

Agtergrond

Hardloop is 'n gewilde keuse vir die rekreasie atleet omdat dit 'n relatief goedkoop sport is, en die beoefening daarvan nie gebonde is aan 'n hoë-tegnologie fassiliteit nie (Mann *et al.*, 1981:190; Wen *et al.*, 1997:1291). Gepaardgaande hiermee is egter 'n styging in die voorkoms van hardloop beserings wat wissel vanaf so laag as 11 persent (Montgomery *et al.*, 1989:239) tot so hoog as 75 persent (Van Mechelen, 1995:161).

In 'n studie deur Marti *et al.* (1988:289), is gevind dat een uit elke vyf hardlopers hul oefenprogram moes onderbreek as gevolg van beserings. Een uit elke sewe het mediese aandag nodig gehad en een uit elke veertig harlopers is genoodsaak om werk te mis. 'n Duidelike stel veranderlikes wat gebruik kan word om die hoë-risiko hardloper te identifiseer sal dus van baie waarde wees in die mediese praktyk (Frederickson, 1996:50; O'Toole, 1992:S360).

Verskeie faktore is al as risikofaktore vir hardloopbeserings geïdentifiseer (Krivickas, 1997:133; Layman & Morris, 1991:33; Montgomery *et al.*, 1989:237; Pinshaw *et al.*, 1984:291; Wen *et al.*, 1997:1292). Hierdie faktore word as intrinsieke of ekstrinsieke faktore beskryf vanweë hul aard (Gellman & Burns, 1996:263). Intrinsieke risikofaktore verwys na die inherente eienskappe van die atleet soos anatomiese belyning en omvang van beweging van 'n gewrig (Krivickas, 1997:135), maar ook na sielkundige faktore (Layman & Morris, 1991:28; Robbins & Joseph, 1985:23) en die spierkrag waardes van die atleet (O'Toole, 1992:S360). Foute in die oefenprogram, verkeerde of foutiewe toerusting en die oppervlaktes waarop geoefen word is aan die ander kant ekstern tot die atleet en word daarom as eksterne risikofaktore geklassifiseer (Krivickas, 1997:133).

Die verband tussen anatomiese belyning en oorgebruiksbeserings in hardlopers is nog nie onomwonde bewys nie, en die resultate van bestaande studies weerspreek mekaar (Krivickas, 1997:133). Onvoldoende spierkrag en wanbalanse in die spierkrag-verhoudings rondom 'n gewrig word ook genoem as belangrike risikofaktore in die etiologie van hardloopbeserings (Jönhagen et al., 1994:226; Kibler et al., 1991:68; O'Toole, 1992:S360).

DOELSTELLING

Hierdie studie het ten doel gehad om die belangrikheid van anatomiese belyning as voorspeller van beserings in 'n groep padatlete te ondersoek en daarmee saam ook die verband tussen spierkrag en beserings in die onderste ledemaat.

METODES

Twee-en-vyftig hardlopers van marathon klubs in die Potchefstroom-Klerksdorp gebied is vir deelname aan die studie gewerf. Die respondente moes 'n toetsbattery deurloop wat bestaan het uit 'n vraelys, 'n standaard voorseisoen mediese ondersoek en die meting van anatomiese belyning, spierkrag in die onderste ledemaat en antropometriese veranderlikes. Daar is van proefpersone verwag om 'n vraelys te voltooi met betrekking tot hul oefenroetine en demografiese inligting. Hardloopbeserings is tydens die mediese ondersoek deur die geneesheer gediagnoseer en aangeteken.

Die volgende faktore is gemeet ten einde 'n idee te verkry van die atleet se anatomiese belyning: voorvoet varus, longitudinale voetboog, voetboog-index ("arch index"), beenlengte verskille, varus of valgus belyning van die knie, Q-hoek, dinamiese heup abduktor spierkrag (Trendelenberg se teken), posterior dy en lae-rug soepelheid (sit-en-reik) en passiewe heup-ekstensie omvang van beweging.

Spierkrag waardes is verkry vir beide konsentriese en eksentriese kontraksies van die spiere rondom die knie en die enkel. Uit hierdie inligting was dit moontlik om die konvensionele sowel as funksionele spierkrag verhoudings te bereken vir knie ekstensie en fleksie, asook vir dorsifleksie en plantaarfleksie van die enkel.

RESULTATE

'n Stel veranderlikes is vir manlike en vroulike proefpersone onderskeidelik geïdentifiseer met behulp van 'n diskriminant analise, wat beseerde atlete baie akkuraat kon voorpsel. In manlike hardlopers kon hierdie faktore beseerde atlete met 94 % akkuraatheid voorspel, en in vroulike met 88 % akkuraatheid. Die stel veranderlikes wat vir manlike respondente geïdentifiseer is sluit in: voorvoet varus, voetboog-indeks, posterior dy en lae-rug soepelheid asook die persentasie liggaamsvet. Veranderlikes met voorspellingswaarde vir vroulike respondente was: voorvoet varus, voetboog-indeks, longitudinale voetboog, varus of valgus belyning van die knie, Q-hoek, die funksionele beenlengteverskil, heup-ekstensie omvang van beweging en die aantal jare wat die respondent al hardloop (ervaring).

Geen verband is gevind tussen spierkrag waardes en hardloopbeserings nie.

GEVOLGTREKKING

Die gevokgtrekking wat hieruit gemaak kan word is dat anatomiese belyning wel 'n belangrike rolspeler in die etiologie van hardloopbeserings is, en dat dit ook voorspellingswaarde kan hê. 'n Interessante opmerking is dat net twee veranderlikes in beide die mans en die dames se voorspellings modelle voorgekom het, naamlik voorvoet varus en voetboog-indeks ("arch index").

Geen verskille is gevind tussen die spierkrag waardes van beseerde en onbeseerde proefpersone nie, en gevolglik kon geen verband tussen die bogenoemde veranderlikes onderskei word nie. Dit wil dus voorkom asof spierkrag in die onderste

ledemaat nie so 'n belangrike rol speel in die etiologie van hardloopbeserings as anatomiese belyning nie.

SLEUTELTERME

hardloop, hardloopbeserings, anatomiese belyning, spierkrag

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LIST OF ABBREVIATIONS

ANATOMICAL ALIGNMENT MEASURES:

AI	-	Arch index
F. Varus	-	Forefoot varus
Hip ext.	-	Hip extension
Knee v/v	-	Knee varus or valgus
LAA	-	Longitudinal arch angle
LLD (A)	-	Anatomical leg length discrepancy
LLD (F)	-	Functional leg length discrepancy
NTH	-	Navicular tuberosity height
Q-angle	-	Quadriceps angle
Sit-&-Reach	-	Sit-and-reach test
Trend.	-	Trendelenberg sign

MUSCLE STRENGTH PARAMETERS:

QconX	-	Average concentric quadriceps strength.
QeccX	-	Average eccentric quadriceps strength.
HconX	-	Average concentric hamstrings strength.
HeccX	-	Average eccentric hamstrings strength.
GconX	-	Average concentric triceps surae strength.
GeccX	-	Average eccentric triceps surae strength.
TconX	-	Average concentric tibialis anterior strength.
TeccX	-	Average eccentric tibialis anterior strength.
HQ con	-	Conventional concentric, hamstrings to quadriceps muscle strength ratio.
HQ ecc	-	Conventional eccentric, hamstrings to quadriceps muscle strength ratio.

TG con	-	Conventional concentric, tibialis anterior to triceps surae muscle strength ratio.
TG ecc	-	Conventional eccentric, tibialis anterior to triceps surae muscle strength ratio.
HeQc	-	Functional eccentric hamstrings, to concentric quadriceps muscle strength ratio.
HcQe	-	Functional concentric hamstrings, to eccentric quadriceps muscle strength ratio.
TeGc	-	Functional eccentric tibialis anterior, to concentric triceps surae muscle strength ratio.
TcGe	-	Functional concentric tibialis anterior, to eccentric triceps surae muscle strength ratio.

ANTHROPOMETRIC AND DEMOGRAPHIC CHARACTERISTICS:

BMI	-	Body Mass Index
% Fat	-	Percentage body fat

TRAINING PARAMETERS:

DistWk	-	Weekly training distance
FlexTr	-	Time spent on flexibility training
Pace	-	Running pace as measured at a time trial.

OTHER:

ITBFS	-	Iliotibial band friction syndrome
MTSS	-	Medial tibial stress syndrome
PF	-	Plantar fasciitis
PFPS	-	Patellofemoral pain syndrome

CONTENTS

1

INTRODUCTION

1.1 Introduction

As the popularity of running as a sport increases, it is not surprising that the incidence of injuries related to running is also increasing (Mann et al., 1981:190; Wen et al., 1997:1291). This ranges from as little as 11 percent (Montgomery et al., 1989:239), to as high as 75 percent (Van Mechelen, 1995:161).

The preferred treatment for running injuries is prevention or early intervention (Frederickson, 1996:50; O'Toole 1992:S360). In order to do this successfully, a clear and trustworthy set of predictor variables is needed that can be used to identify the high-risk runner.

It is therefore understandable that establishing causative relationships between postulated risk factors and running injuries has been the aim of a considerable amount of research (Ballas et al., 1997:2473; Hintermann & Nigg, 1998:169; Jönhagen et al., 1994:262; Renström & Johnson, 1985:317; Krivickas, 1997:133; Layman & Morris, 1991:33; Montgomery et al., 1989:237; O'Toole, 1992:S360; Pinshaw et al., 1984:291; Van Mechelen, 1995:161; Wen et al., 1997:1292).

The various factors that have been identified as contributing towards injuries in runners can be described as being either intrinsic or extrinsic in nature (Gellman & Burns, 1996:263). Extrinsic risk factors refer to training errors such as high weekly training distance and hill or interval running, faulty equipment and training surfaces that are too hard, too soft, uneven or slippery (Krivickas, 1997:133). Intrinsic risk factors on the

other hand are related to the anatomical alignment and joint range of motion of the extremity (Krivickas, 1997:135) and include Q-angle, knee varus/valgus, tibial varus/valgus, foot type, pronation, and leg-length discrepancies. Other intrinsic factors that may predispose a runner to injuries are a negative addiction to running (Layman & Morris. 1991:28; Robbins & Joseph, 1985:23), and muscle-strength imbalances and weakness (O'Toole, 1992:S360).

1.2 Problem statement

The influence of anatomical factors on overuse injuries is not yet completely understood and existing studies often contradict one another (Krivickas, 1997:133). Training errors are often cited to be the major discriminator in the onset of running injuries, but this theory has been questioned in a study by Pinshaw et al. (1984:297). In the above-mentioned study, only 30 percent of injured runners had recently altered their training programme. This led to the conclusion that running injuries definitely do have a biomechanical basis and most probably result from chronic overload due to longstanding biomechanical imbalance (Pinshaw et al., 1984:297).

Other studies found very few statistically significant relationships between alignment measures and injuries (Warren, 1984:62; Warren & Jones, 1987:73; Wen et al., 1997:1295) and concluded that further investigation was needed to evaluate the role of intrinsic risk factors in the aetiology of running injuries.

Inadequate strength and muscular imbalances are also important aetiological factors in the development of running injuries (Jönhagen et al., 1994:226; Kibler et al., 1991:68; O'Toole, 1992:S360). Kibler et al. (1991:70) recently postulated that optimal muscle strength acts to protect the athlete against the onset of injury.

The purpose of this study is to examine retrospectively the importance of anatomical alignment in predicting the risk of overuse injuries in runners. Furthermore, this study will investigate the relationship of muscle strength with injury incidence in runners.

The questions to be answered with this study were: "Can anatomical alignment measures be used to predict running injuries?" and "Are muscle-strength characteristics related to injury?"

The value of this study is that by identifying clinically measurable characteristics that predispose runners to injury, the high risk runner can be identified and preventative measures taken. This will contribute towards lowering the incidence of injuries, as well as the medical costs and possible loss of work time associated with musculoskeletal injury (Marti et al., 1988:289).

1.3 Hypothesis

Research has indicated certain factors to put athletes at risk for injury. The role of anatomical alignment and muscle strength in the aetiology of running injuries is however not well established. The hypotheses being tested in this study are that injuries to runners can be predicted with the use of anatomical alignment measures and that optimal muscle-strength provide an additional protective mechanism against injuries. By examining the anatomical and muscle-strength characteristics of a group of recreational runners, information on the correlation of running injuries with these characteristics will be obtained.

1.4 Objectives

In order to test the hypothesis that has been formulated, a number of objectives have been defined. These objectives include the investigation of anatomical alignment measures, muscle strength and other possible causes for running injuries in order to meet the following aims:

1. To determine if anatomical alignment can accurately predict the allocation of runners in the present study to injured or uninjured groups.

2. To determine the relationship of muscle-strength characteristics with the incidence of running injuries.

1.5 Structure of this dissertation

The results obtained with this study will be presented as follows: The introductory chapter will be followed by a review of the relevant literature in Chapter 2. Chapter 3 will give a detailed description of the study design and the methods used for data collection. Chapter 4 will present the results and a discussion of the results and finally, the conclusions from this study together with future research proposals and practical implications will be given in Chapter 5.

2

IDENTIFYING THE HIGH- RISK RUNNER – A REVIEW OF CURRENT LITERATURE.

2.1 Introduction

Running is without doubt the most fundamental and ubiquitous form of movement in sports (Anderson, 1996:77). Road running is a popular choice of physical activity for many people because of its being a relatively inexpensive sport that is not bound to a specific facility or immovable and often expensive apparatus (Mann *et al.*, 1981:190). It is estimated that in the United States running is enjoyed by approximately 30 million people, of whom 10 million on a regular basis (Gellman & Burns, 1996:263).

People run for many reasons: for example for pleasure, for health and fitness, to relax and to compete (Van Mechelen, 1995:161). Schnohr *et al.* (2000:602), found in a study over five years of 4658 men that persistent joggers had a significantly lower mortality rate than non-joggers or uncommitted joggers.

During running, complex reciprocal movement patterns convert muscular forces into translocation, incorporating nearly all the major joints and muscles in the body (Anderson, 1996:77). Movements in the saggital plane are of the largest amplitude and contribute most to propulsion, but there are more subtle movements in the transverse and frontal planes which provide stabilization and otherwise contribute to propulsion.

The role of the lower extremity in running can be divided into subtasks (Winter & Bishop, 1992:149). During the weight-acceptance phase, the lower extremity is responsible for shock (energy) absorption and control of vertical collapse. It is also responsible for balance and postural control of the upper body, energy generation associated with forward and upward propulsion and control of direction changes during ambulation. A muscle or muscle group can be involved in more than one of these subtasks simultaneously.

Biomechanical studies have shown the ankle to be the major power generator and the knee the major power absorber in running and walking. According to Gellman and Burns (1996:263), these findings correlate well with injury patterns of tendinitis in the Achilles and tibialis posterior tendons, and patellofemoral pain syndrome in the knee.

This is however, contrary to the findings of an electromyographic study conducted by Montgomery *et al.* (1996:272). In this study, the firing pattern of 11 hip and knee muscles was analyzed during running with indwelling electromyographic electrodes.

Montgomery *et al.* (1996:277) found that forward propulsion was provided mainly by hip flexion and knee extension and not, as thought, by the posterior calf muscles. The primary function of the hamstring muscle during running was not knee flexion but the eccentrical control of hip flexion (Montgomery *et al.*, 1996:272). It was assisted in this by the adductor magnus, tensor fascia latae and gluteus maximus, which also function as pelvic stabilizers during hip extension.

In the above-mentioned study, muscle activity was found to increase with faster running speeds. This could put the runner at risk for injury, especially in the muscles that contract eccentrically (Montgomery *et al.*, 1996:277).

The subjects used in this study were 30 recreational runners and not elite or competitive runners as are often seen in studies on runners. They also ran overground and not on a treadmill. The results of this study therefore, may be more readily applicable to the general running population.

2.2 The incidence of running injuries.

During running, each leg absorbs an average of 2 to 3 times the bodyweight for each stride taken. The average amount of strides taken by runners per kilometer is 938 (McKeag & Dolan, 1989:108). For a runner weighing 60 kilograms that would average 112.60 to 168.80 tons per leg, for each kilometer run! With this in mind, it is not surprising that the lower extremity has a high incidence of injuries (Winter & Bishop, 1992:149).

A running injury can be defined as a condition that causes the athlete to decrease his/her weekly training mileage (O'Toole, 1992:S360). Depending on which study is cited, the incidence of running injuries ranges from as little as 11 percent (Montgomery *et al.*, 1989:239), to as high as 75 percent (Van Mechelen, 1995:161). Table 2.1 is a summary of the incidence of running injuries as reported in literature.

Table 2.1: A summary of studies on the incidence of running injuries.

Study	N	Description of population	Injury incidence
Ballas *et al.* (1997:2473)	860	Runners	60.5 %
Jacobs & Berson (1986:152)	451	Entrants to 10 km race	46.6 %
Layman & Morris (1991:28)	1039	Joggers and runners	58.8 %
Lysholm & Wiklander (1987:169)	60	Sprinters, middle distance and marathon runners	65 %
Marti *et al.* (1988:286)	4358	Male joggers	45.8 %
Montgomery *et al.* (1989:239)	505	Navy SEAL trainees	11%
O'Toole (1992:S360)	Review*	Runners	45-70 %
Van Mechelen (1995:161)	Review*	Marathon runners	25-75 %
Wen *et al.* (1997:1294)	304		44.8-56 %

* Information gathered from review articles.

From Table 2.1, the average injury incidence per study can be calculated as 56 percent. It is interesting to note that the study by Montgomery *et al.* (1989:239) had the lowest incidence of running injuries despite the arduous training regimen of the Navy SEALs. The relatively low injury incidence may be ascribed to the high levels of physical activity of trainees before entering the programme.

In a review of ten selected studies on running injuries by Hoeberigs (1992:408), the factors that may relate to the incidence of running injuries were investigated. The differences seen in

injury rates were related to different definitions of running injuries, the length of the observation period and the choice of the subgroup from the total population (Hoeberigs, 1992:419).

Differences in weekly distances run between study populations were not found to be the main reason for differences in incidence rate between these studies. Other factors that may contribute to the differences in injury rates seen between these studies are, the selection mechanism during sampling and an under-or-over representation of aetiological factors as a result of the methodological approach (Hoeberigs, 1992:421).

Patellofemoral pain, iliotibial band friction syndrome, shin splints – these are all examples of terminology used to describe common running injuries. However, due to discrepancies that exist in the literature in defining these injuries, a direct comparison of the most common could not be made. A summary of the most common anatomical locations for running injuries is given in Table 2.2.

Table 2.2: A summary of the most common anatomical locations for running injuries

Study	Ballas *et al.* (1997:2473)	Pinshaw *et al.* (1984:293)	Wen *et al.* (1997:1294)
Anatomical injury site			
Back	0.00 % *	0.00 %	12.00 %
Hip	3.40 %	0.00 %	10.60 %
Upper leg	11.30 %	7.30 %	10.10 %
Knee	17.60 %	51.30 %	28.00 %
Lower leg	17.10 %	30.00 %	13.40 %
Ankle	7.10 %	6.00 %	6.50 %
Foot	4.00 %	5.30 %	19.40 %

* Incidence given as percentage of anatomical injury locations as reported for separate studies.

In these three studies, the knee was consistently found to be the most injured site, followed somewhat less consistently by the lower leg, upper leg, ankle, and foot.

2.3 Causes of running injuries

According to Gellman and Burns (1996:263), running injuries occur from an overload on the muscles, bones, joints and tendons, which is caused by factors that can be described as either intrinsic or extrinsic. Intrinsic factors refer to the runners' anatomy (Krivickas, 1997:133) and psyche whereas extrinsic factors arise mainly from training errors and faulty equipment. Extrinsic risk factors are also referred to as modifiable risk factors (Frederickson, 1996:51) and should play a large role in the intervention programmes used by health professionals (Pinshaw *et al.*, 1984:297).

The intrinsic and extrinsic risk factors that are implicated in the aetiology of running injuries are summarized in Table 2.3.

Table 2.3: A summary of the aetiological factors associated with running injuries

Intrinsic risk factors		Extrinsic risk factors	
1. Muscular	- imbalance - inflexibility	1. Training errors	- insufficient rest between sessions - high weekly mileage - interval training - hill running - pace - flexibility training
2. Anthropometrical	- weight - height - gender		
3. Psychological	- negative addiction to running.	2. Surfaces	- too hard - too soft - uneven or slippery
4. Anatomical Alignment	- pes planus/cavus - hyperpronation - forefoot varus/valgus - rearfoot varus - tibia varum - genu varus/valgus - increased Q angle - lordosis	3. Footwear	- low shock absorbency - wrong design or fit

(Ballas *et al.*, 1997:2473; Hintermann & Nigg, 1998:174; Jönhagen *et al.*, 1994:266; Renström & Johnson, 1985:316; Krivickas, 1997:145; Layman & Morris, 1991:29; McKeag & Dolan, 1989:110; Montgomery *et al.*, 1989:240; Montgomery *et al.*, 1996:277; Pinshaw *et al.*, 1984:297; Van Mechelen, 1995:165; Wen *et al.*, 1997:1295; Winter & Bishop, 1992:155).

2.3.1 Intrinsic risk factors

Intrinsic risk factors have been found by Lysholm and Wiklander (1987:170), to account for 40 percent of overuse injuries.

2.3.1.1 Anatomical alignment

Anatomical factors appear to play an important role in lower extremity injuries (Krivickas, 1997:133) and the publication of James *et al.* (1978:40) was one of the earliest studies that focused the attention of the sports medicine community on this aspect. It is unfortunately true that when all factors contributing to overuse injuries are considered, anatomical factors are the least amenable to correction.

Some controversy exists with regard to which anatomical alignment measures should be used to discriminate between injured and uninjured runners, (Johnson & Gross, 1997:253), as well as how they should be measured. Furthermore, because of the diversity in function of the different structures that are involved in ambulation, the anatomical variables that can be used to predict injury may vary depending on which injury is being studied.

Analysis of three studies (Messier & Pittala, 1988:501; Pinshaw *et al.*, 1984:291;Wen *et al.*, 1997:1291) that investigated the role of anatomical alignment in the aetiology of running injuries revealed some variance in the anatomical alignments studied, as well as in their measurement. Wen *et al.* (1997:1291) retrospectively studied a group of 304 runners enrolling in a marathon training programme. The alignment measurements that were performed included arch index, heel valgus, knee tubercle sulcus angle, knee varus and leg-length difference (Wen *et al.*, 1997:1292).

In the above-mentioned study, minor malalignments were not found to be risk factors for injury in their population; they did find an association between arch index and hamstring and shin injuries, knee varus with hip injuries and leg-length discrepancies with back, ankle and foot injuries (Wen *et al.*, 1997: 1294).

Messier and Pittala (1988:501) similarly studied the relationship between selected biomechanical, anthropometric and training variables in runners afflicted with the

following injuries: Iliotibial band friction syndrome (ITBFS)(N=13), shin splints (N=17), and plantar fasciitis (N=15). These groups were compared to a control group who had no history of running-related injuries. The anatomical alignment measures utilized in this study were a footprint test to evaluate the medial longitudinal arch, the sit-and-reach test, plantar and dorsiflexion range of motion, Q-angle and true and apparent leg lengths (Messier & Pittala, 1988:502).

The only significant discriminator found was between the plantar fasciitis group and the control group with respect to plantar flexion range of motion. Specifically, the plantar fasciitis group exhibited significantly more (7.1°) range of motion in plantar flexion than the control group. A leg-length difference of more than 0.64 cm was also present in 53 percent of the plantar fasciitis group compared to 21 percent in the control group. The ITBFS and shin-splints groups showed a trend towards decreased dorsiflexion range of motion (compared to the control group) and the footprint test revealed slightly higher arches in the ITBFS group (Messier & Pittala, 1988:503).

No differences were found in the flexibility of the lower back and posterior thigh of injured and uninjured runners (Messier & Pittala, 1988:504), suggesting that this may not be a important discriminator for ITBFS, plantar fasciitis and shin splints. The average Q-angle for the injured groups ranged from 13° to 15.92° and was not significantly different from the control group (13.58°) (Messier & Pittala, 1988:504). This can be explained in two possible ways: either Q-angle is not an important aetiological factor in the development of the injury studied, or the value commonly considered abnormal (20°) may be too liberal when used to evaluate runners.

In the study by Wen *et al.*, (1997:1291), the weekly training distance of the subjects was relatively low. At the time of their enrolment in the marathon training programme, which was also the time at which the pre-training questionnaire was administered, their average weekly training distance was 21.92 kilometers (Wen *et al.*, 1997:1293).

Macera (1992:54) found an increase in the injury rate of runners with an increase in the weekly training distance beyond 32 kilometers per week. The runners in the study by Wen *et al.* (1997:1291) therefore might have a lower injury-incidence rate than a group with similar anatomical alignment characteristics but a higher weekly training distance.

The subjects in the study by Messier and Pittala (1988:504) trained an average of between 62.4 and 83.2 kilometers per week but in this study, excessive mileage was not found to be a significant predisposing factor for injury.

The interaction between the weekly training distance and anatomical alignment therefore, warrants further investigation.

Pinshaw *et al.* (1984:291) investigated the causes and response to therapy of 196 consecutive injuries seen at a runners' clinic. The anatomical variables that were investigated included the structural alignment of the lower extremity, patella alignment and leg-length differences. In this study, a leg-length difference was present in 16 percent of the subjects with runners' knee, 14 percent in the shin-splints group and in 37 percent of the runners with ITBFS (Pinshaw *et al.*, 1984:295).

The degree of genu varum was similar for the above-mentioned injury groups and was present in 50 percent of all the injured runners in this study (Pinshaw *et al.*, 1984:295). With regard to patellar alignment, subjects with runners' knee was found to have squinting patellas while 86 percent of the ITBFS group had normal knee alignment. Interestingly, the ITBFS population in this study also displayed normal foot alignment. From this, it can be deduced that ITBFS has a different injury mechanism than runners' knee and shin splints, and that the aetiology may be somewhat more complicated than is currently believed (Pinshaw *et al.*, 1984:297).

These authors also found that approximately 70 percent of the injured runners in this study had not recently changed their training programme. This points to the possibility that injury does not result from training errors but more probably from chronic overload due to longstanding biomechanical imbalance (Pinshaw *et al.*, 1984:297). Viewed in the light of their finding that these injuries responded well to biomechanically-based treatment, this data confirms the importance of anatomical alignment in the aetiology of running injuries.

Warren (1984:64), and Warren and Jones (1987:73) compared a group of runners with plantar fasciitis with an uninjured control group with respect to several anatomical alignment factors. These included leg-length discrepancy, subtalar joint pronation,

ankle plantar and dorsiflexion ability and arch height but in none of these studies a set of predictor variables could be found that could correctly identify the injured groups.

These findings were echoed in a prospective study by Montgomery *et al.* (1989:242), in which several alignment measures in Navy SEAL recruits were investigated. These included hip extension, hip internal and external rotation, knee extension, knee flexion, knee varus/ valgus, Q-angle, ankle dorsiflexion and foot type. None of these measures however, could successfully discriminate between recruits with and without medial tibial stress syndrome.

2.3.1.2 Muscle strength and muscle-strength ratios in the lower extremity

Muscular imbalance around a joint or inadequate strength is an important risk factor for running injuries (O'Toole, 1992:S360) and muscle weakness was associated with plantar fasciitis (Kibler *et al.*, 1991:68) and hamstring injuries (Jönhagen *et al.*, 1994:226) in runners.

In the study by Kibler *et al.*, (1991:68), subjects with plantar fasciitis displayed weakness of the plantar flexors as well as decreased dorsiflexion range of motion. Flexibility deficits as well as ligamentous laxity may predispose an athlete to overuse injuries (Krivickas, 1997:134), and poor flexibility of the triceps surae group (gastrocnemius and soleus) may be a cause of compensatory pronation at the subtalar joint (Prentice, 1999:504). Excessive pronation can in turn be linked to many overuse injuries in runners, especially to the knee (Frederickson, 1996:52)

Kibler *et al.*, (1991:70) found a significant correlation between a decrease in peak torque production and the onset of clinical symptoms. They concluded that adequate muscular strength acts as a protecting factor between relatively symptom-free activity and activity causing symptoms.

2.3.1.3 Anthropometrical factors

It would seem logical that anthropometrical variants could have an influence on sustaining a running injury, but age, gender and body weight were not concluded to be risk factors for running injuries (Hoeberigs, 1992:419; Macera, 1992:55; Marti 1991:38; Van Mechelen, 1992:326; Wen *et al.*, 1997:1295). A sudden gain in bodyweight and obesity was, however, listed as a risk factor for plantar fasciitis by Singh and Angel (1997:175; Marti 1991:21).

2.3.1.4 Psychological factors

Although the response is variable, serum concentrations of endogenous opoids, primarily beta-endorphin or beta-lipotrophin, increase in response to exercise. The elevation of beta-endorphin in exercising men and women has ranged to as high as five times the resting level, with even higher values probably occurring in the brain itself (McArdle, Katch & Katch, 1994:337).

Although the precise physiologic significance of the endorphin response is unclear, the most notable postulated effect has been its role in triggering the so-called "exercise high" – a state of euphoria and exhilaration that is associated with intense exercise. The endorphin effect has also been linked to increased pain tolerance and appetite control, as well as a reduction in anxiety, tension, anger and confusion – all of which are proposed benefits of regular exercise (McArdle, Katch & Katch, 1994:337, Van Mechelen, 1995:161).

If this and the other health benefits that are associated with regular exercise is taken into consideration, adherence to regular exercise can be viewed as a "positive addiction."

A negative addiction could therefore exist if the athlete overtrains in order to keep experiencing these positive effects or in order to avoid experiencing running withdrawal symptoms that are associated with missed training. Robbins and Joseph (1985:23) explored the nature of these withdrawal symptoms. They found that over half of the runners that were forced to stop training suffered irritability, restlessness, frustration, depression, and guilt. In a subsequent study by Layman and Morris

(1991:28) of 1,227 runners and joggers (63,2 % were competitive runners and 36,8 % joggers), 55 percent perceived themselves to be addicted to running and nearly 80 percent of these also reported withdrawal symptoms. A greater proportion of runners as compared to joggers reported both withdrawal and injury occurrence.

In the above-mentioned study, withdrawal and injury occurrence were related and experience of withdrawal symptoms could successfully discriminate between injured and uninjured subjects. When weekly mileage and frequency were statistically controlled for, the withdrawal-injury relationship was removed. This suggests that overtraining is the chief mediator between running withdrawal and more frequent muscle-skeletal injury (Layman & Morris, 1991:28).

2.3.2 Extrinsic risk factors

2.3.2.1 Training errors

Training errors can be summarized as any change in the training schedule that does not allow for sufficient rest (Jacobs & Berson, 1986:154; O'Toole, 1992:S360). These errors have been summarized by McKeag and Dolan (1989:110), as doing "too much, too soon" and are cited by Lysholm and Wiklander (1987:169) to be responsible for 72 percent of the injuries in their study.

The factors that are implicated in training errors usually form an essential part of any fitness programme (Jones *et al.*, 1994:212). These factors include hill and interval running and increasing the weekly training distance (Frederickson, 1996:51; Gellman & Burns, 1996:263; Macera, 1992:56; O'Toole, 1992:S360). In contrast to the above-mentioned authors, Jacobs and Berson (1986:152) found no correlation between running injuries and running hills and intervals, running surfaces and sprints.

The most important risk factor for the development of running injuries seems to be excessive weekly training distance. Macera (1992:54) reports an increase in injury rate with an increase in weekly training distance beyond 32 kilometers per week. Training

distances of between 48 and 62 kilometers per week (Jacobs & Berson, 1986:154) have been cited to increase the risk of sustaining an injury to 50 percent.

According to Gellman and Burns (1996:263), training errors account for approximately 60 percent of running injuries.

2.3.2.2 Surfaces

Training surfaces can also be precursors to overload injuries to the lower extremity (Winter & Bishop, 1992:149). Changing training surfaces (O'Toole, 1992:S360) and running on uneven or cambered roads may also contribute towards running injuries (Prentice, 1999:484). Running on hard surfaces was not found to be a risk factor for running injuries by some authors (Macera, 1992:55; Marti *et al.*, 1988:291; Van Mechelen, 1992:161), but was listed as a risk factor for stress fractures of the foot by Arnheim and Prentice (1997:428).

2.3.2.3 Footwear

Wearing inadequate or worn-out shoes that provide little support or cushioning may contribute to running injuries (Arnheim & Prentice, 1997:125). Footwear is predicted to protect or attenuate the potential damaging forces in three ways, namely shock absorption at heel strike, protection against rough surfaces in the stance phase and by aligning the forefoot at toe-off (Winter & Bishop, 1992:155).

2.4 Lower-limb biomechanics

Distance running has become a popular way to increase physical fitness. The repetitive nature of the activity however necessitates efficient biomechanics in order to remain injury free (Warren, 1984:60).

The importance of anatomical alignment will be reviewed in the light of the biomechanics of a normal running gait, as well as the role of pronation and supination during normal biomechanics and in the aetiology of running injuries.

2.4.1 Normal biomechanics during running

Lower extremity action during a complete stride in running can be divided into two phases. The first is the stance or support phase, which starts with initial contact at heel strike and ends with toe-off (Prentice, 1999:513) and the second is the swing or recovery phase. This represents the time immediately after toe-off during which the leg is moved from behind the body to a position in front of the body in preparation for heel strike.

During the stance phase, the function of the foot is twofold. At heel strike the foot acts as a shock absorber to attenuate impact forces and then adapts to uneven surfaces. At push-off, the foot functions as a rigid lever to transmit explosive force from the lower extremity to the running surface (Arnheim & Prentice, 1997:408; Frederickson, 1996:51; Prentice, 1999:513).

The support phase can be further broken down into foot strike, mid-stance and propulsion (Subotnick, 1985:146). At initial contact, the subtalar joint is supinated and contact takes place on the lateral aspect of the calcaneus (Arnheim & Prentice, 1997:408). Associated with this supination is an obligatory external rotation of the tibia. As the foot is loaded, the subtalar joint moves into a position of passive pronation until the forefoot is in contact with the running surface. The change in subtalar joint motion occurs between initial heel strike and 20 percent into the support phase of running (Prentice, 1999:513). As pronation occurs in the subtalar joint, there is obligatory internal rotation of the tibia and subsequent rotation in the transverse plane at the knee joint (Arnheim & Prentice, 1997:408). At the same time, from initial contact to mid-stance, the pelvis rotates externally with respect to the supporting leg, which is initiating external rotation of the femur (Mann *et al.*, 1981:197)

Pronation continues for approximately 70 percent of the weightbearing phase with maximum pronation occurring at about 40 percent through the support phase into mid-stance, (Frederickson, 1996:51; Arnheim & Prentice, 1997:408), which is approximately when the center of gravity passes over the weightbearing foot.

During mid-stance, the arch is controlled by the metatarsal joint which works in harmony with the subtalar joint (Subotnick, 1985:147; Frederickson, 1996:51). The subtalar joint loosens the foot and the metatarsal joint tightens it and supports the arch.

The foot begins to resupinate and will approach the neutral position at 70 to 90 percent of the support phase. In supination, the midtarsal joints are locked and the foot becomes stable and rigid to prepare for push-off. (Arnheim & Prentice, 1997:408; Frederickson, 1996:51; Prentice, 1999:513).

It is estimated that 80 percent of distance runners use a heel-strike pattern of running and that the remainder are either midfoot or forefoot strikers. Sprinters tend to be forefoot strikers, while joggers are midfoot or heelstrikers (Arnheim & Prentice, 1997:408).

2.4.2 Pronation and supination

Optimal alignment of the leg-heel and heel-foot is with the subtalar joint at, or near its neutral position (Frederickson, 1996:51) and a neutral midtarsal joint at the middle of midstance (Subotnick, 1985:147). There are two dynamic motions that take place about the subtalar joint: pronation and supination. With pronation the foot everts, abducts and dorsiflexes and with supination it inverts, adducts and plantarflexes.

Pronation and supination are essential movements of the foot and subtalar joint during the support phase of running (Arnheim & Prentice, 1997:408). Excessive pronation during the support phase however, or pronation that is prolonged into the propulsive phase of running, will result in an overload of the supporting structures of the foot and leg by requiring additional effort of the involved musculature in an attempt to stabilize the foot during push-off (Arnheim & Prentice, 1997:409; Ballas *et al.*, 1997:2476; Hintermann & Nigg, 1998:172; Messier & Pittala, 1988:504; Viitasalo & Kvist, 1983:130).

Excessive pronation of the subtalar joint during the support phase will not allow the foot to resupinate in time to provide a rigid lever for push-off, resulting in a less powerful and efficient force being applied to the running surface (Prentice, 1999:532).

The increase in tibial rotation occurs simultaneously with external rotation of the pelvis with respect to the supporting leg, which is initiating external rotation of the femur. As these two movements are in opposite directions, the knee is forced to absorb more transverse rotation and this may be associated with potential overloading of the knee (Mann *et al.*, 1981:197; Arnheim & Prentice, 1997:408).

Thus, various foot and leg problems may arise with prolonged or excessive pronation during the support phase. These include stress fractures of the second metatarsal, plantar fasciitis, tibialis posterior tendinitis, Achilles tendinitis, medial tibial stress syndrome and medial knee pain (Arnheim & Prentice, 1997:410).

Structural deformities in the foot or leg are likely to be compensated for at the subtalar joint. This compensation will take place in a manner that allows the foot to make stable contact with the ground and get into an optimal position for weight bearing (Arnheim & Prentice, 1997:409).

Typical structural deformities of the foot that induce compensation at the subtalar joint include forefoot varus, forefoot valgus and rearfoot varus (Arnheim & Prentice, 1997:409; Prentice, 1999:532; Subotnick, 1985:148). Structural forefoot and rearfoot varus deformities are usually associated with excessive pronation (Fig. 2.5). A structural forefoot valgus, on the other hand, causes excessive supination. These deformities will interfere with the normal functions of the foot and make it more difficult for it to act as a shock absorber, to adapt to uneven surfaces and to act as a rigid lever for push-off. It is usually the compensation rather than the deformity itself that causes overuse injuries (Arnheim & Prentice, 1997:409).

Compensatory overpronation may also be caused by a tibia varum, femoral anteversion, leg length difference, forefoot varus or by inflexibility of the triceps surae group (Prentice, 1999:504).

When prolonged or excessive supination is present at heel strike, compensatory movement at the subtalar joint will not allow the midtarsal joint to unlock, which causes the foot to remain rigid. In this position, the foot cannot absorb the ground reaction forces as efficiently

(Arnheim & Prentice, 1997:410). Excessive supination also limits the ability of the tibia to rotate internally.

Injuries that are typically associated with excessive supination include ankle sprains, medial tibial stress syndrome, peroneal tendinitis, iliotibial band friction syndrome, and trochanteric bursitis (Arnheim & Prentice, 1997:410).

Absorption of ground reaction forces occur through the flexion present in the hip and knee joints at heel-strike, dorsiflexion at the ankle (talocrural joint) and pronation at the subtalar joint (Mann *et al.*, 1981:197).

2.5 Etiology of common running injuries

2.5.1 Patellofemoral pain syndrome (PFPS)

Knee injuries comprise approximately 30 to 50 percent of all running injuries, the majority of which are overload injuries involving the patellofemoral joint (O'Toole, 1992:S361). However, the pathophysiology of this syndrome is not well understood (Frederickson, 1996:51). In most runners, some combination of excessive distance or other training errors and the underlying malalignment, apparently cause them to become symptomatic (Messier *et al.*, 1995:957). Steps, hills and uneven surfaces tend to aggravate this condition (Juhn, 1999:2013).

In general, the literature and clinical experience suggest that the etiology of patellofemoral pain syndrome (PFPS), is multifactorial. No single biomechanical factor has been identified as a primary cause of PFPS (Kannus & Niitymäki, 1994:295), although many have been hypothesized. These include pes planus, pes cavus, Q-angle, weakness of the quadriceps and vastus medialis obliquus muscles, or tightness of the hip abductors, adductors and external rotators and tightness of the calf muscles (Juhn, 1999:2013; Kannus & Niitymäki, 1994:289).

A prospective study by Lysens *et al.* (2000:492), identified shortened quadriceps muscle, altered vastus medialis obliquus reflex-response time, a decreased explosive strength and a hypermobile patella as risk factors for the development of PFPS in 282 college students. The subjects in this study participated in a variety of sports and track and field training comprised only 14.3 percent of the total training time per week (Lysens *et al.*, 2000:481). The results of the study may therefore not be as readily applicable to a population of marathon runners.

2.5.2 Iliotibial band friction syndrome (ITBFS)

The incidence of ITBFS relative to all reported injuries that afflict runners ranges from 1.6 to 12 percent (Messier *et al.*, 1995:951; Pinshaw *et al.*, 1984:283).

During knee flexion and extension, the iliotibial band passes in a posterior direction over the femoral condyle at approximately 30 ° of knee flexion (Prentice, 1999:484). This is an action seen repeatedly during running and may produce irritation and inflammation of the tendon.

Clinical surveys and opinions suggested a number of aetiological factors in the development of ITBFS. These include training errors such as excess mileage, a sudden increase in mileage, running on crowned roads and irregular surfaces. Anatomical malalignments include cavus feet, genu varum, tibia varum, rearfoot and forefoot varus and leg-length discrepancies (Pinshaw *et al.*, 1984:296; Prentice, 1999:484). Prentice (1999:484) also lists an inadequate stretching programme as a possible causative factor for the development of ITBFS.

Contractures of the tensor fascia latae and gluteus maximus, tightness of the hamstrings and quadriceps, excessive pronation leading to increased internal rotation of the tibia and a tight Achilles tendon (Prentice, 1999:484), can individually or collectively increase the tension in the iliotibial band.

In contrast to these findings, Messier and Pittala (1988) compared runners with ITBFS with an uninjured cohort of runners on selected anthropometrical, biomechanical and training variables and found no significant discriminators between the two groups. This led Messier *et al* (1991:1013) to speculate on the possibility that weekly mileage might interact with some combination of risk factors to cause injury. Runners that possess the necessary combination of

risk factors typically remain free from injury if their weekly training distance stays below the threshold level.

In a subsequent study Messier *et al.* (1995:951) examined the differences between an uninjured group and a group of runners afflicted with ITBFS according to selected anthropometrical, biomechanical, muscle strength and training variables. The subjects used in this study were 56 runners with ITBFS and 70 uninjured recreational and competitive runners.

A linear discriminant function analysis of training data revealed weekly training distance, training pace, number of months using current training protocol, percentage of time spent on cross training and the percentage of time that is spent on training on the track (Messier *et al.*, 1995:954) to be significant discriminators between injured and uninjured subjects. Height was the only significant anthropometric discriminator (Messier *et al.*, 1995:955), while significantly lower knee extension and flexion strength and endurance measures were found in the ITBFS group (Messier *et al.*, 1995:959). Maximalised braking force was the only kinetic variable that was identified through the discriminant analysis (Messier *et al.*, 1995:956).

A combined discriminant analysis using only those variables that were found to be significant in the previous analyses revealed weekly training distance and maximum normalised braking force to be the best discriminators (Messier *et al.*, 1995:956).

In a cadaveric study, Orchard *et al.* (1996:378) found substantial variation in the width of iliotibial bands. This variation may also affect an individual's predisposition to ITBFS. Because of the reduced knee-flexion angle at foot strike, downhill running may also lead to the development of ITBFS. In contrast, sprinting and faster running speeds on level ground will be less likely to cause or aggravate ITBFS because, at foot strike, the knee is flexed beyond the angles at which friction occurs (Orchard *et al.*, 1996:378).

2.5.3 Medial tibial stress syndrome (MTSS)

According to Viitasalo and Kvist (1983:125), shin splints is a common and harmful problem in runners and has a controversial and multifaceted aetiology.

According to Frederickson (1996:58) athletes that are prone to tibial stress injuries often have a tendency towards reduced ankle dorsiflexion secondary to tightness of the triceps surae complex, a standing-foot-angle of less than 140 degrees, higher incidence of rearfoot and forefoot varus and compensatory hyperpronation.

Viitasalo and Kvist (1983:126) used a combination of three methods to study the position and mobility of the subtalar joint in athletes with MTSS. Comparisons were done with respect to passive mobility of the subtalar joint, the position of the lower leg and heel while standing and the position and angular displacement of the lower leg and heel during treadmill running. Significantly greater values for the MTSS group indicate that the ankle posture during standing and the passive and active mobility of the subtalar joint, are slightly different between sportsmen with and without MTSS (Viitasalo & Kvist, 1983:130).

It must be noted however, that the injured athletes in this study consisted not only of marathon runners, but included other sports e.g. orienteering. The subjects with MTSS also ran approximately 56 kilometers per week less than the control group. A study by Kibler *et al.* (1991:71) shows there are adaptations in musculoskeletal tissue because of repetitive tensile stress during athletic activity. These adaptations are first manifested as decreased flexibility of the involved tissues. The possibility must therefore be considered that the greater subtalar range of motion seen in the athletes with MTSS when compared to the uninjured group in the study by Viitasalo and Kvist (1983:129), may be a manifestation of flexibility deficits in the control group due to increased training volume, rather than true laxity of the subtalar joint in symptomatic subjects.

A combination of training errors - excessive pronation, improper footwear, and a poor conditioning level has also been identified as a primary cause of MTSS (Arnheim & Prentice, 1997:458; Prentice, 1999:503). The soleus and tibialis posterior muscles have been implicated as muscular forces that can stress the fascia and periosteum of the distal tibia during running (Prentice, 1999:503). Lower extremity structural variations such as a rearfoot and forefoot varus can also contribute to excessive subtalar pronation in an attempt to get the medial aspect of the forefoot in contact with the ground in time for push-off.

The magnitude of these forces increases with increased running speed (Montgomery *et al.*, 1996:277), especially with a rearfoot striker. Training on embankments and crowned roads

can increase the tension on the medial aspect of the distal tibia and modifications should be made whenever possible (Prentice, 1999:503).

2.5.4 Stress fractures of the lower extremity

The most common locations of stress fractures in the lower extremity are the tibia, fibula, calcaneus (Arnheim & Prentice, 1997:160) and in the foot the navicular, second and fifth metatarsal bones (Prentice, 1999:540). It is unclear if stress fractures are due to increased load on the bone after fatigue of the supporting structures, or caused by the contractile forces created by the muscles that act across and on the bone (Frederickson, 1996:67).

Montgomery *et al.* (1989:237) conducted a study on 505 military recruits (male) in an attempt to identify factors that may predispose to stress fractures. Information was gathered on their training and injury history, as well as their weekly training distance prior to enrolling in the programme. An orthopedic examination was conducted that included hip extension, hip internal and external rotation, knee extension and flexion, Q-angle, knee varus, dorsiflexion range of motion, and foot type (Montgomery *et al.*, 1989:238).

Approximately 11 percent of the population sustained a training-related injury, including a 6.3 percent incidence of stress fractures. Of these, tibial stress fractures accounted for 84.4 percent, femoral stress fractures for 12.5 percent and metatarsal stress fractures for 3.1 percent (Montgomery *et al.*, 1989:239).

Weekly training distance, in this study, seemed to have a sparing effect on the development of stress fractures (Montgomery *et al.*, 1989:242). Subjects who trained at least 40 kilometers per week had a lower incidence of stress fractures (3.0 %) than subjects averaging less than 6.4 kilometers per week (11.5 %). Those running between 6.4 and 40 kilometers per week had a 5.0 percent incidence. Only 19.8 percent of the subjects reported regularly running 40 kilometers or more per week (Montgomery *et al.*, 1989:240). It is therefore understandable that the majority of stress fractures occurred during the first month when the first week of training included running 33.6 kilometers (Montgomery *et al.*, 1989:239).

No other orthopedic-history question, or measurement, or combination of these could discriminate between the groups (Montgomery *et al.*, 1989:240). A factor that may influence the reliability of these findings is the under-diagnosing of stress fractures due to methodological insufficiency and the high motivation of trainees to graduate (Montgomery *et al.*, 1989:242).

2.5.4.1 Stress fractures of the tibia and fibula

Stress fractures of the tibia and fibula are common overuse injuries in distance runners (Arnheim & Prentice, 1997:459, Montgomery *et al.*, 1989:237). The most common location for stress fractures is the midanterior and posteromedial aspect of the tibia, and the distal one-third of the fibula (Prentice, 1999:499).

Stress fractures in the lower leg usually result from the inability of the bone to adapt to the repetitive loading that occurs during training and conditioning of the athlete (Prentice, 1999:499). Again, excessive compensatory pronation at the subtalar joint is cited to be a causative factor for stress fractures.

According to Arnheim and Prentice (1997:459), the athlete with hypermobile feet is more susceptible to stress fractures of the fibula through the repeated action of the foot everters and calf musculature pulling on the bone (Prentice, 1999:500). The athlete with a more rigid pes cavus foot would be more prone to tibial stress fractures (Arnheim & Prentice, 1997:459).

Stress fractures of the anteromedial tibia are exacerbated by repetitive jumping activities and stress fractures of the distal posteromedial tibia by excessive compensatory pronation (Prentice, 1999:500). When running on a crowned road, hyperpronation may be accentuated in the "uphill-leg." Running on a track with a small radius and tight curves will also tend to increase the pronatory stresses of the leg that is closest to the inside of the track (Prentice, 1999:500).

Training errors of increased duration and intensity along with worn-out shoes, lack of experience or conditioning, amenorrhea in female athletes and nutritional deficits

(Arnheim & Prentice, 1997:460) as well as decreased bone density, increased hip external rotation, tibial width and calf girth (Prentice, 1999:500) will only serve to accentuate these problems.

2.5.4.2 Stress fractures of the foot

Excessive pronation is implicated in stress fractures of the navicular and second metatarsal and a more rigid pes cavus in stress fractures of the fifth metatarsal bone (Prentice, 1999:541).

Stress fractures of the navicular and second metatarsal bone are associated with rearfoot and forefoot varus, excessive pronation, training errors, changes in the training surface, inappropriate shoes and the presence of a Morton's toe deformity. Overuse, acute inversion, or high-velocity rotational forces may cause stress fractures of the fifth metatarsal (Prentice, 1999:540).

2.5.5 Achilles tendinitis

The Achilles tendon is subjected to tension of up to ten times bodyweight during running (Frederickson, 1996:60) and injuries to the Achilles tendon have been found to account for 11 percent of all injuries reported by runners (James *et al.*, 1978:45).

According to Arnheim and Prentice (1997:448), Achilles-tendon injury is most often the result of a lack of coordination between the agonist and antagonist muscles after ankle sprains or sudden excessive dorsiflexion of the ankle.

The role of muscle strength in the posterior calf musculature was investigated by Alfredson *et al.* (1998:360). In this study, 15 male and female recreational runners with chronic Achilles tendinitis were evaluated with respect to plantar flexor strength and running activity. Care was taken to eliminate the influence of pain on strength testing by only testing the muscle in a pain free range of motion (Alfredson *et al.*, 1988:365). The symptoms of the subjects in this study were so severe that no running activity could be tolerated.

They were also found to have significantly lower concentric and eccentric plantar flexion strength, when compared to the uninjured leg. This strength deficit may be acquired during the period of inactivity, before the strength measurements, but one could assume that a period of inactivity would affect both extremities (Alfredson *et al.*, 1998:365).

Excessive subtalar pronation with the associated internal rotation of the tibia secondary to a forefoot varus, tibia varum or femoral anteversion will increase the tensile load on the medial aspect of the Achilles tendon. Decreased triceps surae flexibility can also increase subtalar joint pronation in order to compensate for the decreased closed-kinetic-chain dorsiflexion that is needed during the early and mid-stance phase of running (Kibler *et al.*, 1991:69; Prentice, 1999:504).

Repetitive weight-bearing activities, such as running and training errors will aggravate the condition (Kvist, 1994:178; Prentice, 1999:504).

Marti *et al.* (1988:285) used a survey-questionnaire design to investigate the incidence, site, and nature of running injuries among entrants to a 16-kilometer race. Achilles-tendon injuries were the most common single chronic overuse injury in this study population and was found to be significantly and positively correlated with age, weekly mileage, and previous injury (Marti *et al.*, 1988:289).

Other factors that may lead to an Achilles-tendon injury are improper footwear, history of trauma, increased age, gender (male) and bodyweight and height (Kvist, 1994:178; Marti *et al.*, 1988:287).

2.5.6 Plantar fasciitis

Plantar fasciitis is the most common cause of inferior heel pain in distance runners (Sing & Angel, 1997:172; Prentice, 1999:541; Bazzoli & Pollina, 1989:55), and accounts for 7 to 9 percent of all running injuries (Frederickson, 1996:62).

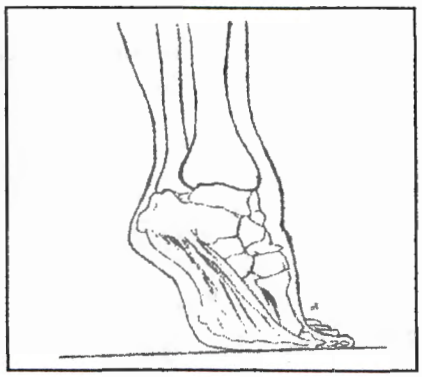

Figure 2.1 The plantar fascia

The function of the plantar aponeurosis (Fig. 2.1) is to assist in the stability of the foot and in securing or bracing the medial longitudinal arch (Prentice, 1999:541).

Tension develops in the plantar fascia with extension of the toes and depression of the longitudinal arch as a result of weight bearing. In ordinary standing, when the weight is principally on the heel, the tension exerted on the fascia is negligible. However, when the weight is shifted to the ball of the foot (on the metatarsal heads), fascial tension is increased. Because the propulsive phase of running involves both a forceful extension of the toes and a powerful thrust on the ball of the foot, the tension in the plantar fascia can increase to approximately twice the athlete's body weight (Prentice, 1999:541).

The prevailing opinion about the causes of plantar fasciitis is that it is biomechanical (Bazzoli & Pollina, 1989:56) and pes planus is the abnormality that is most frequently associated with the condition. Prolonged hyperpronation, as seen with pes planus, will place increased stress on the origin of the plantar fascia on the calcaneus (Frederickson, 1996:62). Subsequently, other factors that increase pronation may contribute to the development of plantar fasciitis. Tightness of the Achilles tendon and triceps surae muscles, leg-length discrepancies, inflexibility of the longitudinal arch, wearing restrictive shoes or shoes without sufficient arch support, a lengthened stride and running on soft surfaces are all potential causes of plantar fasciitis (Frederickson, 1996:63; Kibler *et al.*, 1991:68; Prentice, 1999:541).

Trauma to the plantar fascia may also result from poor running technique, or because of lordosis. In this condition the anterior tilt of the pelvis produces an unfavorable angle of foot strike when there is considerable force exerted on the ball of the foot (Prentice, 1999:542).

Warren (1984:60) and Warren and Jones (1987:71), in separate studies, investigated the anatomical factors that are associated with predicting plantar fasciitis in runners. The variables that were investigated in the first study included leg-length discrepancies, subtalar joint pronation (as measured from the neutral position), dorsiflexion range of motion, arch height and arch height in a loaded stance (Warren, 1984:60). In a subsequent study, Warren and Jones (1987:71) also measured leg-length discrepancies, calcaneal pronation and supination, abduction and adduction of the midtarsal joint, arch height, duration of foot contact on the treadmill, footstrike pattern and calcaneal pronation during running.

Although these two authors in no way examined all the possible anatomical and biomechanical factors that may be involved with plantar fasciitis, neither could find an accurate set of predictor variables (Warren, 1984:61; Warren & Jones, 1987:73). From these results Warren and Jones (1987:73) concluded that despite the clinical value that the identification of a set of predisposing variables might have, plantar fasciitis might be the result of problems other than anatomical or biomechanical.

The strength and flexibility characteristics of the muscles that are put under strain during running (in subjects with plantar fasciitis) were examined by Kibler *et al.* (1991:66). In this study 43 athletes with plantar fasciitis were compared to 45 athletes with no symptoms. The results of the study showed a very high incidence of weakness and inflexibility of the posterior calf muscles (Kibler *et al.*, 1991:68).

Kibler *et al.* (1991:69) speculated that tightness in the posterior structures causes the heel to remain in a valgus position at heel strike and during push-off, thereby restricting midfoot supination and ankle dorsiflexion during the last part of the stance phase and early push-off. Weakness of the plantar flexors may further increase tensile loading on the muscle and ligament attachments by failing to provide proper propulsion during push-off. This causes a functional biomechanical deficit that becomes pathological when it is coupled with other factors, such as anatomical pronation or training errors.

Increased pronation has been shown not to be a valid predictor for athletes who will develop plantar fasciitis (Warren, 1984:61; Warren & Jones, 1987:73). The concept of a biomechanical deficit that causes functional pronation (Kibler *et al.*, 1991:70) helps to explain the presence of clinical symptoms when only a small percentage of injured athletes show anatomical hyperpronation. These authors subsequently concluded that adequate muscle strength might act as a protecting factor between relatively symptom-free activity and the development of symptomatic plantar fasciitis (Kibler *et al.*, 1991:70).

It should be mentioned however that the subjects in this study, who were long distance runners, comprised 81 percent of the plantar fasciitis group and only 11 percent of the control group. The results that were thus obtained through comparison may not be reflective of the symptom-free running community. The authors also failed to take into account the possible influence of other factors associated with running injuries such as training errors and anthropometrical variables. These limitations suggest that the results of this study shouldn't be directly applied to injured runners, but definitely warrant further investigation.

2.6 Summary

From the literature review, it appears that there are many possible ways in which anatomical alignment and muscle strength can contribute to running injuries. Figure 2.2 is a schematic

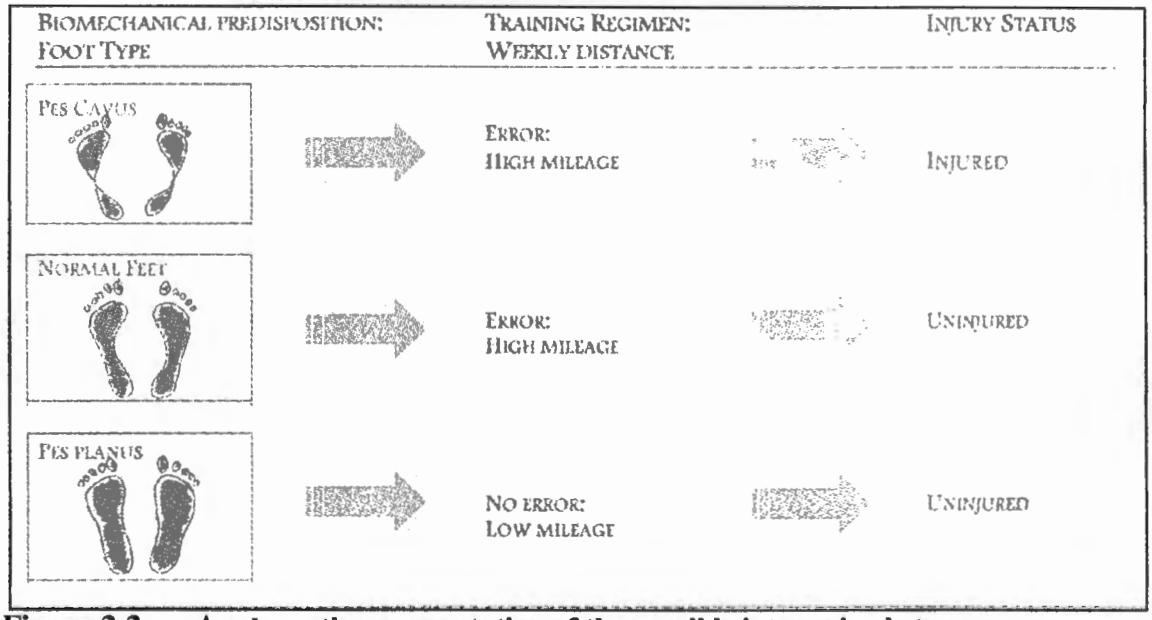

Figure 2.2 A schematic representation of the possible interaction between

representation of the possible interaction between anatomical alignment and training errors to precipitate an injury.

3

RESEARCH METHODS

3.1 Introduction

The aim of this study was firstly to determine if anatomical alignment measures can accurately predict running injuries and secondly to determine the relationship between muscle-strength characteristics and the incidence of injuries. Because of the possible influence of training errors and anthropometric variables on the development of injury, these were also assessed with appropriate measurements.

The parameters that were investigated were chosen on the grounds of their being relatively easy and inexpensive to test and, with the exception of the muscle-strength measurements, require equipment that is common to a Biokinetics Centre.

The results of this study will be presented in Chapter 4.

3.2 Literature review

For the literature review, information was sought on running injuries and risk factors that predispose athletes to injury. The following databases were consulted: Sport Discus, Medscape, Medline, and Index Medicus.

3.3 Research design

This study made use of a observational cross-sectional design as described by Thomas and Nelson (1990:286).

3.4 Subjects

Volunteer subjects (n=52), for this study were aged 19-60 years and were all members of marathon or running clubs from the Potchefstroom-Klerksdorp area. The subjects included 33 males and 19 females.

Possible participants were screened telephonically (Addendum A), and were included in the study if they had been participating in running or running-related activities for at least one year and trained a minimum weekly distance of 8 kilometers. Subjects had to be older than 16 years and signed an informed consent document (Addendum C) explaining the procedures, possible risks, and discomforts.

Conditions for exclusion from the study were known cardiac pathology, angina, muscle or joint conditions worsened by physical activity (e.g. fibromyalgia, arthritis), chronic or degenerative conditions (e.g. muscular dystrophy), the use of certain medications and if female, pregnancy. Pre-test instructions were also given at this time (Addendum B).

Subjects did not receive payment for their participation.

3.5 Procedures and apparatus used for data collection

3.5.1 Reliability of the measurements

The reliability and validity of anatomical alignment measures is not well established (Jonson & Gross, 1997:258). In a study by Jonson and Gross (1997:253) nine anatomical alignment measures were investigated with respect to their intraexaminer and interexaminer reliability.

These measures were found to be reliable for the population studied, when conducted by experienced examiners (Jonson & Gross, 1997:262).

With this in mind, a pilot study was conducted to familiarize examiners with the measurement procedures. The test re-test reliability of the measurements used in this study were however not established. Great care was taken to perform measurements in accordance with a standardized protocol, and the same examiners were asked to measure the total population.

Clinical measurements are generally performed by relatively inexperienced practitioners, with little or inadequate training in this specialized. It is therefore the opinion of the author that although the measurements may not be statistically reliable, it nevertheless is a reliable reflection of clinical practice.

3.5.2 Instrumentation

Demographic, anthropometric, orthopedic and muscle-strength data were collected on a data-collection sheet developed for this study (Addendum D). A plastic goniometer, ruler and measuring tape were used for the orthopedic measurements and plastic skinfold calipers for measuring percentage body fat. A Detecto scale and an anthropometer were used for the assessment of bodyweight and height, respectively.

A standard sit-and-reach bench was used to measure hamstring and lower-back flexibility. Muscle strength was measured with a Kin-Com isokinetic dynamometer (Chattex Corporation, Chattanooga, Tennessee).

3.5.3 Questionnaire

Subjects were required to complete a questionnaire (Addendum D), with respect to the following:

- Age
- Gender

- Experience
- Surface
- Weekly training distance
- Best time recorded over 5 kilometers at a race or official club time trial (Pace)
- Amount of time spent on flexibility training (stretching) for the lower extremity

3.5.4 Physical testing

Subjects were evaluated on the following:

3.5.4.1 Standard pre-season medical examination

A standard, pre-season medical examination was made. The physician was also asked to diagnose and record injuries (Addendum E).

3.5.3.2 Anthropometric measurements

- **BODYWEIGHT AND HEIGHT**

Height was measured with an anthropometer mounted on a Detecto scale and weight with a calibrated beam-type Detecto scale.

- **BODY MASS INDEX**

The Body Mass Index was calculated by dividing body weight in kilogrammes by height in meters squared (wt/ht^2) (ACSM, 1995:58).

- **PERCENTAGE BODY FAT**

Body composition determined from skinfold measurements correlates well with body composition determined by hydrostatic weighing (ACSM, 1995:55). In this study percentage body fat for male and female subjects was determined by a six skinfold formula, specific to the athletic population (Withers *et al.*, 1987:178; Whithers *et al.*, 1987:197).

3.5.3.3 Anatomical alignment measurements

The following anatomical alignments were measured: forefoot varus, longitudinal arch angle, arch index, leg-length discrepancy, knee varus/ valgus, Q-angle, hip abductor strength (Trendelenberg test), posterior thigh and lower-back flexibility (sit-and-reach), and hip extension range of motion.

The alignment measures included in this study were chosen because they have been previously implicated as possible risk factors and because they are relatively easy and inexpensive to measure. This would ensure that results obtained will be of practical value for the Sports Medicine community.

- **FOREFOOT VARUS**

This measurement was taken with the subject in the prone position on the plinth and the feet extending over the edge. The medial and lateral heads of the talus were then palpated and the foot manipulated through inversion and eversion until the neutral position was found (both heads could be palpated equally) (Brukner & Khan, 1993:58; Prentice, 1999:535). The examiner then placed one thumb under the fourth metatarsal head and gently moved the foot into a position of neutral (0 degrees dorsiflexion), while keeping the talus in its neutral position. In this position the angle between a line bisecting the calcaneus and a line connecting the first metatarsal with the fourth, was measured with a goniometer.

The average degree of forefoot varus was calculated for both feet and recorded.

- **LONGITUDINAL ARCH ANGLE**

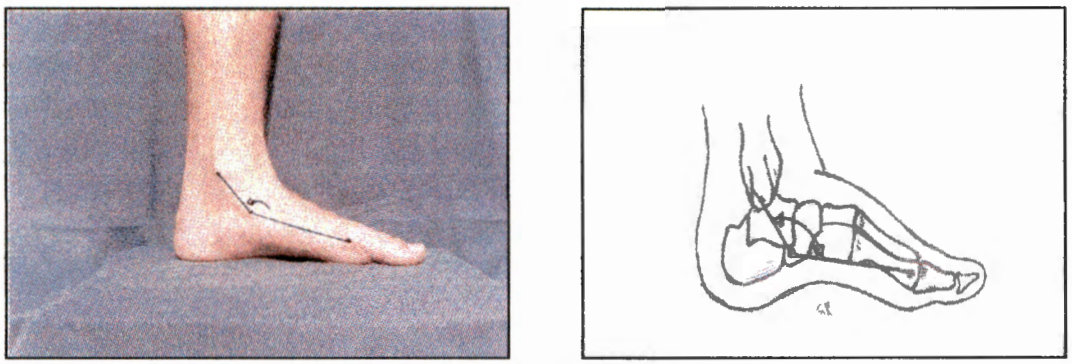

Figure 3.1 The measurement of longitudinal arch angle

The longitudinal arch angle was measured as the angle formed between a line connecting the medial malleolus and the navicular tuberosity and one connecting the navicular tuberosity to the most medial aspect of the first metatarsal head (Johnson & Gross, 1997:256). A goniometer was used for these measurements.

The average value for both feet was calculated and recorded.

- **ARCH INDEX**

A ruler was used to measure the perpendicular distance from the navicular tuberosity to the floor, while the subject was standing. Foot length was measured from the most posterior aspect of the calcaneus to the medial side of the first metatarsophalangeal joint (Warren, 1984:60; Warren & Jones, 1987:71). The arch index was then calculated as the ratio of the navicular height to the foot length.

The values obtained for both feet were averaged and recorded.

- **LEG-LENGTH DISCREPANCY**

Anatomical leg-length was measured with the subject in the supine position on the plinth. The knee and hip joint were in full extension. Measurement was taken between the anterior superior iliac spine and the lateral malleolus of each leg as described by Arnheim and Prentice (1997:536).

Functional leg length was measured in the position described above, but measurement was taken as the distance from the umbilicus to the medial malleolus of each leg (Arnheim & Prentice, 1997:536).

In both cases leg-length discrepancy was then calculated by subtracting the smaller value from the larger for each leg. The average leg-length discrepancy for both legs was then calculated and recorded.

- **KNEE VARUS/VALGUS**

The method used to measure knee varus/valgus was an adaptation of the method described in the study of Montgomery *et al.* (1989:238).

The subject stood and attempted to place his feet as close together as possible. In this position the distance between the medial malleoli, and the distance between the medial femoral epicondyles were recorded.

The relative degree of knee varus/valgus was then computed by subtracting the malleoli distance from the condylar distance. In this way, a positive number indicated knee varus, and a negative, knee valgus.

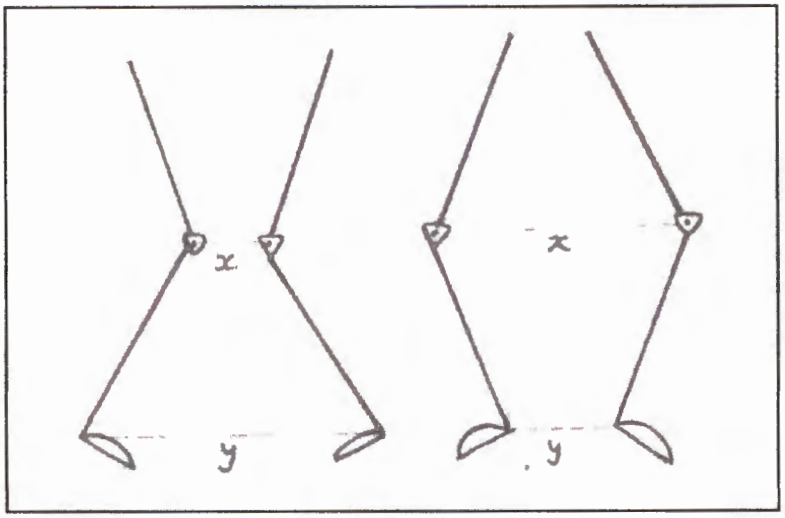

Figure 3.2 The measurement of knee varus/ valgus alignment

- **Q-ANGLE**

The method used in this study was adapted from the one described by Arnheim & Prentice (1997:488), where the angle was measured with the athlete in the supine position.

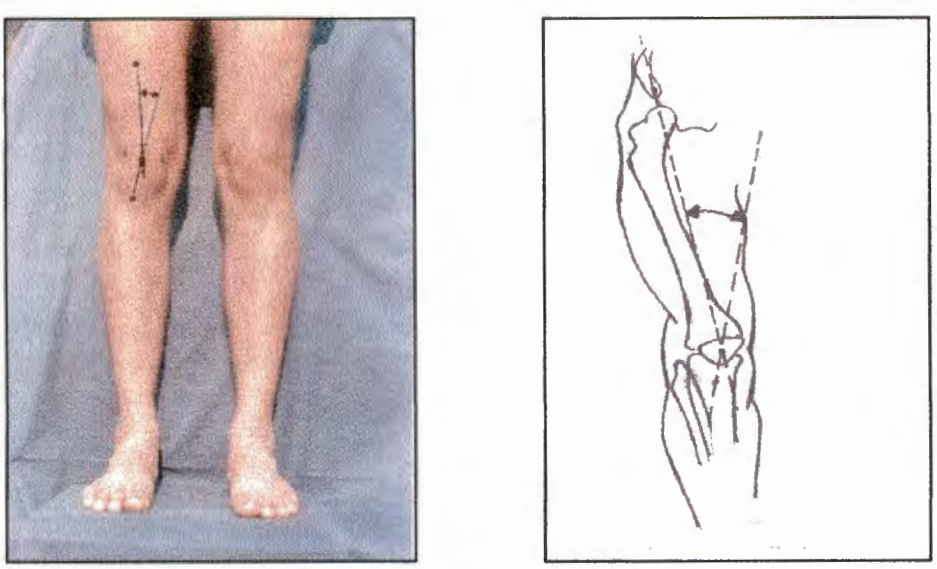

Figure 3.3 The measurement of Q-angle

In this study, the Q-angle was measured standing with the knee in comfortable extension, in order to obtain a more dynamic measure of patellar alignment. The patella was palpated and the medial and lateral borders marked with a pen. The

superior and inferior patellar poles were palpated and marked in the same way. The midpoint of the patella was then determined as the place where lines connecting these points bisected each other and was marked. The anterior tibial tubercle was palpated and marked, as was the anterior superior iliac spine.

The examiner then connected the anterior superior iliac spine to the midpoint of the patella with a plastic measuring tape. A line was then drawn along the tape on the anterior aspect of the subject's upper leg, to connect these anatomic landmarks. A line connecting the anterior tibial tubercle to the midpoint of the patella was then extended (to the upper leg) with a ruler.

The standing Q-angle was then measured as the angle formed between these two lines. The average Q-angle for both legs was obtained and recorded.

- **HIP ABDUCTOR STRENGTH (TRENDELENBERG SIGN)**

The Trendelenberg test evaluates gluteus medius strength (Hoppenfeld, 1976:164). The subject was observed from behind while standing. In this position the posterior superior iliac spines should be level. The subject was then asked to stand on one leg.

If the gluteus medius on the supported side contracted and elevated the pelvis on the unsupported side, a classification of a negative Trendelenberg sign was given. If the pelvis on the unsupported side remained in place or dropped, the gluteus medius muscle on the supported side was either weak or nonfunctioning and this was then classified as a positive Trendelenberg sign.

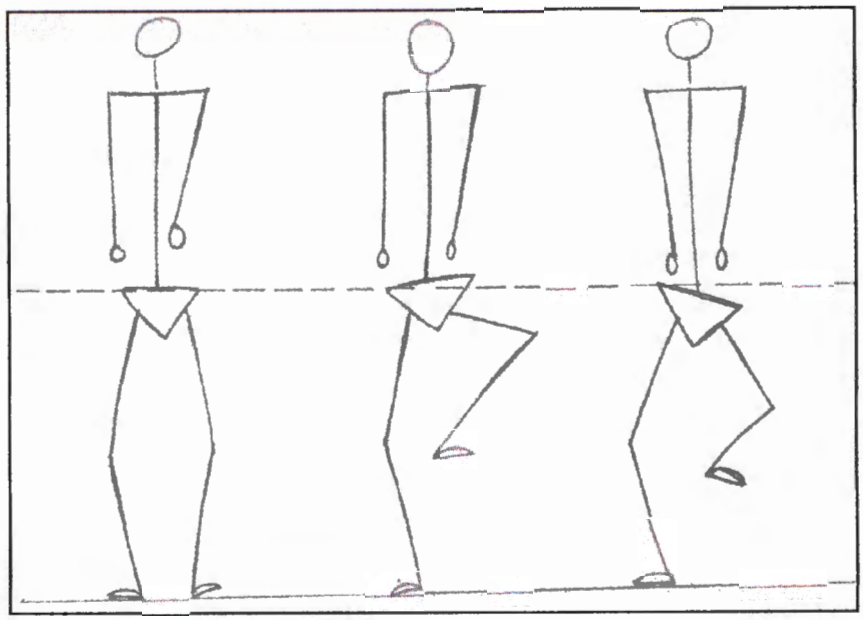

Figure 3.4 The Trendelenberg sign for weak dynamic hip abductor strength

For statistical analysis, a value of 1 was ascribed to a positive Trendelenberg sign (weak hip abductors), and a value of 0 to a negative Trendelenberg sign.

- **POSTERIOR THIGH AND LOWER-BACK FLEXIBILITY (SIT-AND-REACH TEST)**

A wooden sit-and-reach bench was used to measure hamstring and lower-back flexibility (Prentice, 1999:289). The subject sat with knees fully extended on the floor, with the ankles in 0 degrees dorsiflexion against the side of the box. With the arms and hands in full extension, the athlete was instructed to lean forward as far as possible without flexing the knees. The subject had to be able to hold the end position for 3 seconds, and 3 attempts were given of which the best score was then recorded.

- **PASSIVE HIP EXTENSION RANGE OF MOTION**

The subject was prone with the hips and knees in neutral and the feet extended over the edge of the plinth. During the measurement, the subject was instructed to keep the knee in extension and the pelvis on the surface of the plinth. The goniometer axis was placed over the greater troganter of the femur, the stationary arm parallel to the midaxillary line of the trunk and the moveable arm parallel to the longitudinal axis of the femur, pointing to the lateral epicondyle. The hip was then extended to the limit of

motion and the angle between the midaxillary line and the longitudinal axis of the femur measured (Clarkson & Gilewich, 1989:242).

Measurements from both legs were averaged and recorded.

3.5.3.4 Isokinetic strength measurements

Subjects were evaluated for knee (N=47), and ankle (N=48), strength. Maximal concentric and eccentric muscle strength were obtained by measuring maximal force moments (torque), during isokinetic knee extension and flexion, as well as ankle plantarflexion and dorsiflexion movements. A Kin-Com isokinetic dynamometer (Chattex Corporation, Chattanooga, Tennessee) was used for the measurements.

Each subject was encouraged verbally and visually by following the torque curve displayed on the screen. This has been found to maximize results (Kellis & Baltzopoulos, 1996:124).

- **KNEE EXTENSION AND FLEXION**

The subject was seated and reclined 10 degrees with a hip angle of approximately 110 degrees. The axis of rotation for the dynamometer lever arm was visually aligned with the lateral femoral epicondyle, and the lower leg was attached to the lever arm at the level of the lateral malleolus. No correction was made for the effect of gravity on torque.

The hips, upper body, and the thigh to be tested were firmly strapped to the dynamometer bench. During the test, the subject held his arms folded over his chest. These measures serve to eliminate possible "trick" or substitute movements that may influence the force measured.

Measurement was preceded by a warm-up of five submaximal contractions at 80 deg/sec, during which the subject acquainted himself with the test and contraction mode. Peak concentric and eccentric moments for the hamstrings and quadriceps

muscles were each measured during 3 maximal contractions at 60 deg/sec. The peak torque values, which referred to the maximal torque attained during each contraction mode, were averaged for both legs and used for further calculations.

Concentric testing of both legs was completed before eccentric testing, thus allowing a period of rest between contraction modes.

Range of motion for knee extension and flexion ranged from 95 degrees knee flexion to 0 degrees knee flexion (indicating knee extension).

- **ANKLE PLANTAR AND DORSIFLEXION**

The subject was seated and reclined 10 degrees. The knee was flexed to approximately 15 degrees, and the upper leg was supported on a leg-rest. The axis of rotation for the dynamometer lever arm was visually aligned with the lateral malleolus and the foot of the ankle to be tested was attached to the lever arm by way of a brace. No correction was made for the effect of gravity on torque.

The subject's hips, upper body and the leg to be tested were firmly strapped to the seat. The subject held his arms folded over his chest during the test. These measures serve to eliminate possible "trick" or substitute movements that may influence the force measured.

Measurement was preceded by 5 submaximal contractions at 60 deg/sec, during which the subject acquainted himself with the test and the contraction mode. Peak concentric and eccentric moments for the triceps surae and the tibialis anterior muscles were obtained during 3 maximal contractions (for each mode), at 30 deg/sec.

The peak torque values, which referred to the maximal torque attained within each contraction mode, were recorded and used for further calculations.

A rest period was created by completing concentric testing of both legs before eccentric testing.

The ankle dorsiflexion and plantarflexion range of motion ranged from 17 degrees dorsiflexion to 50 degrees plantarflexion.

3.5.3.5 Conventional hamstrings to quadriceps strength ratio

The conventional hamstrings to quadriceps ratio (HQcon : HQecc), determined as maximal hamstrings moment divided by maximal quadriceps moment (Aagaard *et al.*, 1998:231), was calculated separately for each contraction mode. The average of both legs from each subject was calculated seperately for each contraction mode and recorded.

3.5.3.6 Functional hamstrings to quadriceps strength ratio

The functional hamstrings to quadriceps ratio representative for knee extension (Hecc : Qcon), was determined as maximal eccentric hamstrings moment divided by maximal concentric quadriceps moment. The functional hamstrings : quadriceps ratio for knee flexion (Hcon : Qecc) was determined as maximal concentric hamstrings moment divided by maximal eccentric quadriceps moment (Aagaard *et al.*, 1998:236). Conversely, the functional hamstrings: quadriceps ratio for knee extension (Hecc : Qcon) was determined as maximal eccentric hamstrings moment divided by maximal concentric quadriceps moment.

The average functional ratio for both legs was then calculated separately for knee extension and flexion and recorded.

3.5.3.7 Conventional tibialis anterior to triceps surae strength ratio

The conventional tibialis anterior (TA) to triceps surae (TS) ratio, determined as maximal TA moment divided by maximal TS moment (adapted from Aagaard *et al.*, 1998:231), was calculated separately for each contraction mode. The average of both

ankles from each subject was calculated separately for each contraction mode and recorded.

3.5.3.8 Functional tibialis anterior to triceps surae strength ratio

The functional tibialis anterior (TA) to triceps surae (TS) ratio representative for ankle plantarflexion (TAecc : TScon), was determined as maximal eccentric tibialis anterior moment divided by maximal concentric triceps surae moment. The functional tibialis anterior : triceps surae ratio for ankle dorsiflexion (TAcon : TSecc), was determined as maximal concentric tibialis anterior moment divided by maximal eccentric triceps surae moment (adapted from Aagaard *et al.*, 1998:236).

The average of both ankles from each subject was calculated separately for plantarflexion and dorsiflexion and recorded.

3.6 Research procedures

The study was approved by the Research Board of the School for Biokinetics, Recreation and Sportsciences in the Faculty Health Sciences at the Potchefstroom University for Christian Higher Education.

The project was explained to members of marathon clubs and running clubs in the Potchefstroom - Klerksdorp area. Volunteers were then screened (telephonically) concerning certain criteria for participation in the study (Addendum A). Pre-test instructions were also given at this time (Addendum B).

The researchers conducting this study were students and personnel of the Institute for Biokinetics at the PU for CHE, as well as a sports physician. All testing was performed at the Institute and was concluded within 6 weeks. Measurements were taken carefully and particular attention was paid to measurement technique.

At the time of the testing, all procedures and possible risks and discomforts were explained to each subject individually and written informed consent was obtained. Testing was divided into five stations and was conducted in the following sequence: questionnaire, medical examination, anthropometric measurements, orthopedic measurements and strength testing.

3.7 Statistical Analyses

The information gathered in the study was analyzed with the CSS: Statistica (Microsoft Corporation, 1986) computer package. The means and standard deviations were obtained by way of descriptive statistics. To determine whether there were significant differences between male and female and injured and uninjured subjects, independent t-tests were performed. The p-value for significance was set at $P<0.05$. A Pearson product-moment correlation was done to correlate all variables with one another and a discriminant analysis was used to identify the variables that could best predict running injuries.

4

RESULTS AND DISCUSSION

4.1 Introduction

The first aim of this study is to discern a relationship between anthropometric and orthopedic variables and the incidence of injuries to the lower extremity in runners. Studies suggest that injuries may be caused by a variety of factors (Ballas *et al.*, 1997:55; Van Mechelen, 1995:19; Frederickson, 1996:21; Renström & Johnson, 1985:317). These factors can be classified as being either intrinsic or extrinsic in nature and can be further divided into anthropometric and demographic characteristics, training parameters, anatomical alignment measures and muscle-strength characteristics.

In order to determine the importance of the postulated relationship to other causative factors in this study, as many of these as were practically possible and cited by literature to have an influence on the development of injuries, were assessed.

4.1.1 Statistical procedures

The importance of anatomical alignment measures in predicting running injuries was determined with a discriminant analysis. This was done separately for male and female subjects. The variables that were used in the discriminant analysis included training and

anthropometric parameters (e.g. experience and percentage body fat), but variables that may be influenced by injury (e.g. muscle strength) were not used. Results of the discriminant analysis are given in Tables 7-12.

The second aim of this study is to determine whether there is a relationship between muscle-strength characteristics and the incidence of running injuries. Muscle-strength values for injured and uninjured runners were compared by way of independent t-tests for male and female subjects, respectively.

A Pearson product-moment correlation was then done to ascertain the presence of underlying relationships between variables that may relate in particular to injury incidence and anatomical alignment measures or muscle-strength characteristics.

4.2 Descriptive statistics

4.2.1 Anthropometrical characteristics and training parameters

Descriptive data was obtained from 52 runners of whom 63 % were male and 37 % female. The proportion of female runners in this study is high in relation to the probable sex ratio of runners in the Cape Town area (Pinshaw *et al.*, 1984:294). In a 10-km race in Cape Town that attracted 700 runners, only 6 % were female. There were also more female runners in the present study than in the study on injured runners (14 %) by Pinshaw *et al.* (1984:294). This serves to complement their conclusion that female runners in South Africa may be more prone to running injuries, less likely to enter 10-km races, or that they are more likely to seek medical attention than their male counterparts.

Of the total population 51.9 % were older than 30 years of age and only 12.1 % were younger than 20. The remainder, (36 %) were aged between 20 and 29 years. This is almost identical to the age distribution in the study by Pinshaw *et al.* (1984:294) where 52 % of runners were above the age of 30 and correlates well with the age distribution in studies by Jacobs and

Berson (1986:152), and Wen *et al.* (1997:1293) in which the average age of runners was 33.2 and 41.1 years, respectively.

At the time of the study, there were 51 injuries in 26 of the runners, for an incidence of 50 % (26/52). These findings echo those of other studies citing the incidence of running injuries, as can be seen in Table 2.1 in Chapter 2. The average amount of injuries for the total population was 0.98 (51/52) injuries per runner, and 1.96 (51/26) for each runner in the injured group. It was not uncommon for a runner to have more than one injury.

The knee was the most common anatomical locality of injury, accounting for 41.2 % of all injuries, followed by the lower leg (21.6 %) and ankle (15.7 %). The finding that the knee is the most frequently injured joint in a population of runners is a tendency that was also reflected in the studies by Ballas *et al.* (1997:2473), Pinshaw *et al.* (1984:293) and Wen *et al.* (1997:1294). Medial tibial stress syndrome (MTSS) was the most common injury seen (19.6 %), followed by ITBFS (17.6 %), PFPS (15.7 %) and Achilles tendinitis (15.7 %). Stress fractures of the tibia and metatarsal bones were noted in only two runners, as was plantar fasciitis and infrapatellar fat pad impingement. Lower-back injuries occurred in only four subjects and the type of injury was not consistent. Less frequent knee injuries included insertional tendinitis of the pes anserinus tendon and inflammation of the knee plicae.

The means, ranges and standard deviations of anthropometric measurements, demographic characteristics, and training parameters for the total population is given in Table 4.1.

Table 4.1: The means, ranges and standard deviations of anthropometric measurements, demographic characteristics and training parameters for the total population.

Parameter	N	Mean	Minimum	Maximum	SD
Weight (kg)	52	71.16	51.00	100.00	12.02
Height (cm)	52	172.99	155.40	192.00	9.24
BMI (kg/m²)	52	23.42	19.90	28.80	2.33
% Fat	52	13.47	5.70	29.70	5.98
DistWk (km)	52	40.42	4.00	120.00	20.89
Pace (km/min)	52	4.52	3.00	7.80	1.01
FlexTr (min)	52	8.92	0.00	20.00	6.81
Injuries	52	0.96	0.00	9.00	1.49

BMI - Body Mass Index
% Fat - Percentage body fat
DistWk - Weekly training distance in kilometers per week
FlexTr - Amount of time spent on flexibility training (stretching)
Pace - Running pace as measured at a time trial

As a group, the Body Mass Index (BMI) of runners in this population was in the "desirable" range for adult men and women (American College of Sports Medicine, 1995:59). They ran at a faster pace than the subjects in the study by Wen *et al.* (1997:1293) (4.52 min/km vs. 6.63 min/km) and trained more (40.42 km/week vs. 21.9 km/week) than those subjects did. From this it can be concluded that the runners in the present study are probably more competitive than those studied by Wen *et al.* (1997:1293), but not as competitive as the runners studied by James *et al.* (1978:43) and Jacobs and Berson (1986:152), who averaged 78.4 and 60.2 km/week respectively. It should be noted that the measurement of running pace in the present study was done during a time trial, whereas the runners in the study by Wen *et al.* (1997:1294) recorded their training pace.

A lack of running experience was also cited to contribute towards injuries (Ballas *et al.*, 1995:19; Hoeberigs, 1992:13; Macera, 1992:13; Marti, 1991:11; Van Mechelen, 1992:14) and was therefore assessed through a questionnaire. The population in this study appears to be relatively experienced with only 30.2 % having participated in running or running-related activities for less than 3 years, and 32.7 % for more than 10 years.

Participants (92.3 %) in this study practiced mainly on hard surfaces, e.g. tar and asphalt, with 3.8 % practicing on grass and 1.9 % on cement. A comparison of the descriptive statistics for male and female subjects by way of an independent t-test is given in Table 4.2.

Table 4.2: Results of an independent t-test to distinguish between the anthropometric and demographic characteristics and training parameters of male and female subjects.

	Gender						
Parameter	**Male**			**Female**			**P**
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	
Weight (kg)	33	77.51	9.87	19	60.14	5.83	0.0001*
Height (cm)	33	177.89	7.03	19	164.49	5.80	0.0001*
BMI (kg/m²)	33	24.12	2.40	19	22.21	1.64	0.0034*
% Fat	32	10.00	3.52	19	19.32	4.51	0.0001*
DistWk (km)	32	42.75	22.93	18	36.28	16.43	0.2977
Pace	30	4.13	0.74	17	5.24	1.06	0.0001*
(km/min)	33	7.88	6.50	18	10.83	7.12	0.1400
FlexTr (min)	33	1.12	1.75	19	0.68	0.89	0.3147
Injuries							

*P<0.05
BMI - Body mass index
% Fat - Percentage body fat
DistWk - Weekly training distance in kilometers per week

FlexTr - Amount of time spent on flexibility training (stretching)
Pace - Running pace as measured at a time trial

As can be expected, significant differences were found between anthropometric variables and the running pace of male and female subjects (Table 4.2). Both genders however trained equal distances, spent similar amounts of time on stretching (flexibility training) and reported an equal amount of injuries.

4.2.2 Anatomical alignment measures

Anatomical alignment factors appear to play an important role in the development of injuries to the lower extremity (Krivickas, 1997:133). A summary of the anatomical alignment measures for the total population of runners in this study is given in Table 4.3.

The subjects in the present study exhibited less lower-back and posterior thigh flexibility (sit-and-reach test) (41.24 cm vs. 46.36 cm) and a smaller average Q-angle (12.51° vs. 14.16°) than the runners in the study by Messier and Pittala (1988:503). The average Q-angle for injured runners in the above-mentioned study (1988:503) ranged from 13.00° to 15.92° and did not differ significantly from the 13.58° recorded for the control group. The values recorded for the total population in this study reflect their findings and support the conclusion that Q-angle may either not be an important risk factor for injury, or that the value commonly considered as abnormal (20°), may be too liberal when evaluating the long-distance running community.

Table 4.3: The means, ranges and standard deviations of anatomical alignment measures for the total group.

Parameter	N	Mean	Minimum	Maximum	SD
Sit-and-reach (cm)	51	41.24	12.00	62.80	10.26
Hip extension (degrees)	52	25.91	11.50	38.50	5.86
Forefoot varus (degrees)	50	6.40	3.00	12.00	2.36
Longitudinal arch angle (degrees)	52	147.38	128.00	168.00	8.87
Arch index	50	0.27	0.18	0.35	0.04
Leg-length Discrepancy(cm)					
Anatomical	52	0.43	0.00	3.90	0.62
Functional	52	0.24	0.00	1.00	0.26
Q-angle (degrees)	52	12.51	3.50	21.50	4.26
Knee varus/ valgus (cm)	52	0.58	-3.00	4.00	1.34

An average arch index of 0.27 was calculated for runners in this study, which is slightly higher than the 0.23 of runners in the study by Wen *et al.* (1997:1293). Leg-length discrepancies and knee varus/ valgus could not be compared to other studies, due to differences in the methodology used to measure these variables.

The results of an independent t-test to determine the presence of gender differences in the anatomical alignment measures are given in Table 4.4.

Although the mean Q-angle values for male and female subjects are within the normal range (Arnheim & Prentice, 1997), female subjects had a significantly larger Q-angle than male subjects, which is consistent with literature. Female runners also displayed a negative knee varus/ valgus count, which suggests a tendency towards knee valgus in female runners and knee varus in male runners.

Table 4.4: Results of an independent t-test to determine gender-related differences in anatomical alignment measures.

Gender							
Parameter	**Male**			**Female**			**P**
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	
Sit-and-reach(cm)	32	39.10	8.44	19	44.85	12.16	0.0522
Hip extension (degrees)	33	24.86	5.73	19	27.74	5.78	0.0888
Forefoot varus (degrees)	31	6.03	2.17	19	7.00	2.59	0.1612
Longitudinal arch angle (degrees)	33	146.15	9.67	19	149.50	7.03	0.1930
Arch index	31	0.27	0.04	19	0.27	0.04	0.7968
Leg-length discrepancy (cm)							
Anatomical	33	0.47	0.71	19	0.37	0.41	0.5951
Functional	33	0.24	0.27	19	0.24	0.24	0.9672
Q-angle (degrees)	33	11.02	3.93	19	15.11	3.57	0.0005*
Knee varus/ valgus (cm)	33	0.92	1.39	19	-0.01	1.05	0.0148*

*P<0.05

Dynamic hip abductor strength was assessed with the Trendelenberg sign (Hoppenfeld, 1976:164) and 84.2 % of the total population were diagnosed with weak gluteus medius muscles.

4.2.3 Muscle strength and muscle-strength ratios in the lower extremity

Inadequate muscle strength and imbalance of agonist and antagonist muscles around a joint are important risk factors for running injuries (Jönhagen *et al.*, 1994:226; Kibler *et al.*, 1991:68; O'Toole, 1992:S360). The means, ranges and standard deviations of average strength values and strength ratios are presented in Table 4.5.

Forty-seven subjects were tested for upper-leg strength and 48 for lower-leg strength. No studies could be found in the literature that attempted to determine normative values for average muscle strength, or muscle-strength ratios in a population of marathon runners. Furthermore, the average strength values and ratios found in the present study differed significantly from those obtained in a population of track and field athletes in a study by Aagaard *et al.* (1998:233). These differences may be due to methodological insufficiency in either study, or it could be a reflection of the highly sport-specific nature of muscle strength and optimal strength ratios.

Table 4.5: The means, ranges and standard deviations for muscle-strength values and strength ratios (conventional and functional) in the lower extremity, for the total population.

Parameter	N	Mean	Minimum	Maximum	SD
QconX (Nm)	47	415.98	202.50	619.00	108.75
QeccX (Nm)	47	547.99	212.00	863.50	161.52
HconX (Nm)	47	272.63	152.50	440.00	70.44
HeccX (Nm)	47	353.06	190.00	715.50	110.80
GconX (Nm)	48	763.18	301.50	1450.00	267.93
GeccX (Nm)	48	1252.13	423.00	1901.50	379.46
TconX (Nm)	48	415.00	155.50	646.50	118.95
TeccX (Nm)	48	551.74	178.50	909.50	178.12
HQ con (Nm)	47	0.67	0.42	1.08	0.12
HQ ecc (Nm)	47	0.70	0.36	1.51	0.25
TG con (Nm)	48	0.60	0.31	1.09	0.17
TG ecc (Nm)	48	0.47	0.20	0.98	0.15
HeQc (Nm)	47	0.86	0.54	1.21	0.16
HcQe (Nm)	47	0.53	0.33	1.02	0.15
TeGc (Nm)	48	0.79	0.29	1.44	0.24
TcGe (Nm)	48	0.36	0.18	1.02	0.14

QconX - Average concentric quadriceps strength.
QeccX - Average eccentric quadriceps strength.
HconX - Average concentric hamstrings strength.
HeccX - Average eccentric hamstrings strength.
GconX - Average concentric triceps surae strength.
GeccX - Average eccentric triceps surae strength.
TconX - Average concentric tibialis anterior strength.

TeccX - Average eccentric tibialis anterior strength.
HQ con - Conventional concentric, hamstrings to quadriceps muscle-strength ratio.
HQ ecc - Conventional eccentric, hamstrings to quadriceps muscle-strength ratio.
TG con - Conventional concentric, tibialis anterior to triceps surae muscle-strength ratio.
TG ecc - Conventional eccentric, tibialis anterior to triceps surae muscle-strength ratio.
HeQc - Functional eccentric hamstrings, to concentric quadriceps muscle-strength ratio.
HcQe - Functional concentric hamstrings, to eccentric quadriceps muscle-strength ratio.
TeGc - Functional eccentric tibialis anterior, to concentric triceps surae muscle-strength ratio.
TcGe - Functional concentric tibialis anterior, to eccentric triceps surae muscle-strength ratio.

An independent t-test was done to determine the presence of gender differences in the muscle-strength measurements as well as in the strength ratios. The results are presented in Table 4.6.

The results of the independent t-test showed statistically significant differences for maximal strength values, but not for muscle-strength ratios. Male subjects were on average 68.1 % stronger than their female counterparts for all the muscle groups measured, both concentrically and eccentrically.

Table 4.6: Results of an independent t-test to determine gender-related differences in muscle-strength values and strength ratios (conventional and functional), in the lower extremity.

Gender							
Parameter	**Male**			**Female**			**P**
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	
QconX (Nm)	29	462.61	93.11	18	340.83	89.62	0.0001*
QeccX (Nm)	29	614.40	150.53	18	441.00	116.74	0.0001*
HconX (Nm)	29	309.22	55.01	18	213.67	49.76	0.0001*
HeccX (Nm)	29	388.05	109.74	18	296.69	89.01	0.0047*
GconX (Nm)	30	899.10	220.43	18	536.64	169.21	0.0001*
GeccX (Nm)	30	1397.35	327.83	18	1010.08	339.88	0.0003*
TconX (Nm)	30	481.97	84.45	18	303.39	76.46	0.0001*
TeccX (Nm)	30	652.10	139.72	18	384.47	83.72	0.0001*
HQ con (Nm)	29	0.69	0.14	18	0.64	0.07	0.1495
HQ ecc (Nm)	29	0.69	0.25	18	0.71	0.24	0.7968
TG con (Nm)	30	0.58	0.14	18	0.62	0.21	0.3901
TG ecc (Nm)	30	0.50	0.15	18	0.43	0.15	0.1026
HeQc (Nm)	29	0.85	0.17	18	0.87	0.13	0.5713
HcQe (Nm)	29	0.54	0.16	18	0.51	0.13	0.4503
TeGc (Nm)	30	0.80	0.24	18	0.79	0.25	0.9172
TcGe (Nm)	30	0.38	0.15	18	0.34	0.12	0.2915

*P<0.05
QconX - Average concentric quadriceps strength.
QeccX - Average eccentric quadriceps strength.
HconX - Average concentric hamstrings strength.
HeccX - Average eccentric hamstrings strength.
GconX - Average concentric triceps surae strength.
GeccX - Average eccentric triceps surae strength.
TconX - Average concentric tibialis anterior strength.
TeccX - Average eccentric tibialis anterior strength.
HQ con - Conventional concentric, hamstrings to quadriceps muscle-strength ratio.
HQ ecc - Conventional eccentric, hamstrings to quadriceps muscle-strength ratio.

TG con - Conventional concentric, tibialis anterior to triceps surae muscle-strength ratio.
TG ecc - Conventional eccentric, tibialis anterior to triceps surae muscle-strength ratio.
HeQc - Functional eccentric hamstrings, to concentric quadriceps muscle-strength ratio.
HcQe - Functional concentric hamstrings, to eccentric quadriceps muscle-strength ratio.
TeGc - Functional eccentric tibialis anterior, to concentric triceps surae muscle-strength ratio.
TcGe - Functional concentric tibialis anterior, to eccentric triceps surae muscle-strength ratio.

4.3 Determining the predictive value of anatomical alignment measures

In order to determine which variables could most accurately identify injured subjects, a discriminant analysis was done using anatomical alignment measures as well as training and morphologic parameters. Only variables that could not be influenced by the presence of an injury (e.g. muscle strength) were used.

Male and female predictor models were calculated separately and will be discussed in the same way. Identical sets of variables were used for both the male and the female analyses.

4.3.1 Results of the discriminant analysis for male subjects

Table 4.7 is a summary of the variables that were used in the discriminant analysis for male subjects.

Table 4.7: Results of the discriminant analysis for male subjects.

Variables included	Variables excluded
Forefoot varus	Experience
Arch index	Weight
Trendelenberg sign	Body mass index
Sit-and-reach	Hip extension
Percentage body fat	Longitudinal arch angle
	Footlength
	Navicular tuberosity height
	Q-angle
	Knee varus/ valgus
	Anatomical leg-length discrepancy
	Functional leg-length discrepancy

The variables that could best identify injured runners in the male group were forefoot varus, the Trendelenberg sign, the sit-and-reach test, percentage body fat and arch index. These

variables could predict uninjured and injured runners with an accuracy of 83.33 % and 93.75 %, respectively (Table 4.8).

Table 4.8: Results of the classification matrix for male subjects.

Group	Percent correct	Uninjured p= 0.42857	Injured p= 0.57143
Uninjured	83.33	10	2
Injured	93.75	1	15
Total	**89.29**	11	17

In Table 4.9 the means and standard deviations of these variables are compared for injured and uninjured runners.

Table 4.9: Comparison of the means and standard deviations obtained for the variables included in the model for male subjects.

	Groups				
	Uninjured		Injured		Difference
Variables	Means	SD	Means	SD	
Forefoot varus (degrees)	4.92	1.68	6.81	2.32	1.89
Arch index	0.27	0.03	0.26	0.05	0.01
Trendelenberg sign	0.92	0.29	0.69	0.48	0.23
Sit-and-reach (cm)	34.98	8.30	42.33	7.89	7.35
Percentage body fat	8.90	1.79	10.94	4.18	2.04

From Table 4.9, it can be seen that the differences between injured and uninjured male subjects are not always large. The degree of forefoot varus in injured subjects was only 1.89° higher than the average for uninjured subjects and the arch index of injured subjects only 0.01 lower than the comparative value for uninjured subjects. Injured male subjects could reach 7.35 cm further than uninjured subjects (indicating increased posterior thigh and lower-back flexibility) and displayed a higher body fat percentage (2.04 %) than uninjured subjects.

Interestingly, uninjured male subjects tended to have weaker dynamic hip abductor strength (Trendelenberg sign) than injured subjects did. This may be an indication that greater movement ("instability") of the pelvis during running and consequently gluteus medius weakness may in fact be necessary to protect the runner against injury.

4.3.2 Results of the discriminant analysis for female subjects

The results of the discriminant analysis for female subjects are presented in Table 4.10.

Table 4.10: Results of the discriminant analysis for female subjects.

Variables included	Variables excluded
Forefoot varus	Trendelenberg sign
Arch index	Percentage body fat
Longitudinal arch angle	Weight
Knee varus/ valgus	Body mass index
Q-angle	Sit-and-reach
Functional leg-length discrepancy	Footlength
Hip extension	Navicular tuberosity height
Running experience	Anatomical leg-length discrepancy

The predictor variables obtained for female runners differed significantly from that obtained for the male runners in this study. The only variables that were included in both the male and female models were forefoot varus and arch index. Other variables that could successfully identify injured female subjects were longitudinal arch angle, knee varus/ valgus, Q-angle, a functional leg-length discrepancy, hip extension range of motion and running experience.

Table 4.11: Results of the classification matrix for female subjects.

Group	Percent correct	Uninjured p= 0.5556	Injured p= 0.4444
Uninjured	100.00	10	0
Injured	87.50	1	7
Total	**94.44**	11	7

The variables identified in the discriminant analysis for female runners could predict uninjured and injured runners with an accuracy of 100 % and 87.5 % respectively. In Table 4.12 a comparison of the means and standard deviations of these variables is made for injured and uninjured subjects.

Table 4.12: Comparison of the means and standard deviations obtained for the variables included in the model for female subjects.

	Groups				
	Uninjured		Injured		Difference
Variables	Means	SD	Means	SD	

Arch index	0.25	0.04	0.29	0.29	0.04
Forefoot varus (degrees)	6.35	2.45	8.19	2.45	1.84
Longitudinal arch angle (degrees)	147.25	5.62	152.44	8.32	5.19
Knee varus/valgus (cm)	0.10	0.32	-0.15	1.63	0.25
Functional leg-length discrepancy (cm)	0.26	0.18	0.16	0.27	0.10
Experience	3.30	1.89	3.88	1.96	0.58
Hip extension (degrees)	28.65	6.42	27.00	5.46	1.65
Q-angle (degrees)	15.00	3.27	14.44	3.57	0.56

Similar to that of male subjects, the differences between injured and uninjured female subjects seem small. Injured female subjects had a larger degree of forefoot varus (1.84°), a higher arch index (0.04) and a larger longitudinal arch angle (5.19°) than uninjured subjects. Other variables showed a tendency in injured subjects towards a knee valgus alignment, a smaller functional leg-length discrepancy (0.10 cm), degree of hip extension (1.65 °) and Q-angle (0.56°). Uninjured subjects tended to have slightly less experience, but both groups have been running regularly for 2 to 3 years.

4.3.3 Summary

Because of significant differences in the anthropometric variables that were included, the discriminant analyses were done separately for male and female subjects. The variables that were identified were very accurate in predicting both injured and uninjured runners in both male and female subjects and the conclusion can be made that these separate sets of variables may be of use in predicting injuries in runners.

The only variables that were included in both the male and female models were forefoot varus and arch index. The results of an independent t-test (Table 4.4), revealed no significant differences between male and female subjects for these two anatomical alignment measures, but the average degree of forefoot varus in uninjured male subjects was 4.92° and in uninjured female subjects 6.35°. The degree of forefoot varus for both male and female subjects in the injured group was approximately 1.86° larger than that of the uninjured subjects. Injured subjects (male and female) furthermore also recorded higher arch index values than uninjured subjects.

The small differences measured between injured and uninjured runners of both sexes again point to the importance of subtle malalignments in the development of injuries in a sport that has a repetitive nature.

4.4 The relationship of muscle-strength characteristics with injuries

In order to determine the influence of muscle strength on injuries, an independent t-test was done to ascertain significant strength discrepancies between injured and uninjured subjects. This was done seperately for male (Table 4.13) and female (Table 4.14) subjects.

Table 4.13: Results of an independent t-test to compare muscle-strength values and strength ratios (conventional and functional) in the lower extremity between injured and uninjured male subjects.

Group							
Parameter	**Uninjured**			**Injured**			**P**
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	
QconX (Nm)	13	447.86	83.90	16	474.59	101.06	0.4524
QeccX (Nm)	13	631.62	142.69	16	600.41	159.82	0.5880
HconX (Nm)	13	317.58	53.71	16	302.44	56.85	0.4712
HeccX (Nm)	13	373.39	89.34	16	399.97	125.55	0.5264
GconX (Nm)	14	929.04	250.41	16	872.91	195.01	0.4962
GeccX (Nm)	14	1422.54	275.63	16	1375.31	375.27	0.7011
TconX (Nm)	14	493.00	91.76	16	472.31	79.23	0.5128
TeccX (Nm)	14	657.43	124.56	16	647.44	155.72	0.8490
HQ con (Nm)	13	0.72	0.10	16	0.67	0.15	0.3011
HQ ecc (Nm)	13	0.61	0.13	16	0.75	0.31	0.1235
TG con (Nm)	14	0.55	0.15	16	0.58	0.13	0.9034
TG ecc (Nm)	14	0.48	0.12	16	0.52	0.17	0.5454
HeQc (Nm)	13	0.83	0.11	16	0.86	0.21	0.7075
HcQe (Nm)	13	0.53	0.15	16	0.56	0.18	0.6630
TeGc (Nm)	14	0.80	0.27	16	0.80	0.21	0.9902
TcGe (Nm)	14	0.37	0.10	16	0.40	0.19	0.7060

*P<0.05

QconX - Average concentric quadriceps strength.
QeccX - Average eccentric quadriceps strength.
HconX - Average concentric hamstrings strength.
HeccX - Average eccentric hamstrings strength.
GconX - Average concentric triceps surae strength.
GeccX - Average eccentric triceps surae strength.
TconX - Average concentric tibialis anterior strength.
TeccX - Average eccentric tibialis anterior strength.
HQ con - Conventional concentric, hamstrings to quadriceps muscle-strength ratio.

HQ ecc - Conventional eccentric, hamstrings to quadriceps muscle-strength ratio.
TG con - Conventional concentric, tibialis anterior to triceps surae muscle-strength ratio.
TG ecc - Conventional eccentric, tibialis anterior to triceps surae muscle-strength ratio.
HeQc - Functional eccentric hamstrings, to concentric quadriceps muscle-strength ratio.
HcQe - Functional concentric hamstrings, to eccentric quadriceps muscle-strength ratio.
TeGc - Functional eccentric tibialis anterior, to concentric triceps surae muscle-strength ratio.
TcGe - Functional concentric tibialis anterior, to eccentric triceps surae muscle-strength ratio.

The results of the independent t-test show that injured and uninjured male subjects do not differ significantly concerning muscle-strength measurements. This is in contrast to the current view in the Sports Medicine community, who cite that strength discrepancies, imbalances and deficits are important risk factors for injuries in athletes (James *et al.*, 1978; Jönhagen *et al.*, 1994: O'Toole, 1992).

In Table 4.14 the results of an independent t-test are presented that compare muscle-strength values and muscle-strength ratios in the lower extremity between injured and uninjured female subjects.

Table 4.14: Results of an independent t-test to compare muscle-strength values and strength ratios (conventional and functional) in the lower extremity between injured and uninjured female subjects.

Group							
Parameter	**Uninjured**			**Injured**			**P**
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	
QconX (Nm)	10	326.00	77.02	8	359.38	105.67	0.4491
QeccX (Nm)	10	451.15	113.19	8	428.31	127.64	0.6929
HconX (Nm)	10	200.90	33.40	8	229.63	63.68	0.2344
HeccX (Nm)	10	265.30	46.20	8	335.94	115.46	0.0948
GconX (Nm)	11	531.45	199.13	7	544.79	122.12	0.8763
GeccX (Nm)	11	946.36	327.63	7	1110.21	359.51	0.3336
TconX (Nm)	11	207.05	70.65	7	355.79	54.79	0.0151*
TeccX (Nm)	11	357.50	87.41	7	426.86	60.79	0.0863
HQ con (Nm)	10	0.63	0.08	8	0.65	0.07	0.6752
HQ ecc (Nm)	10	0.61	0.10	8	0.83	0.32	0.0510
TG con (Nm)	11	0.58	0.22	7	0.70	0.18	0.2626
TG ecc (Nm)	11	0.41	0.13	7	0.44	0.19	0.7289
HeQc (Nm)	10	0.83	0.12	8	0.93	0.14	0.1284
HcQe (Nm)	10	0.47	0.11	8	0.56	0.14	0.1201
TeGc (Nm)	11	0.76	0.28	7	0.84	0.22	0.5534
TcGe (Nm)	11	0.31	0.09	7	0.37	0.16	0.3402

*P<0.05

QconX - Average concentric quadriceps strength.
QeccX - Average eccentric quadriceps strength.
HconX - Average concentric hamstrings strength.
HeccX - Average eccentric hamstrings strength.
GconX - Average concentric triceps surae strength.
GeccX - Average eccentric triceps surae strength.
TconX - Average concentric tibialis anterior strength.
TeccX - Average eccentric tibialis anterior strength.

HQ con -	Conventional concentric, hamstrings to quadriceps muscle-strength ratio.
HQ ecc -	Conventional eccentric, hamstrings to quadriceps muscle-strength ratio.
TG con -	Conventional concentric, tibialis anterior to triceps surae muscle-strength ratio.
TG ecc -	Conventional eccentric, tibialis anterior to triceps surae muscle-strength ratio.
HeQc -	Functional eccentric hamstrings, to concentric quadriceps muscle-strength ratio.
HcQe -	Functional concentric hamstrings, to eccentric quadriceps muscle-strength ratio.
TeGc -	Functional eccentric tibialis anterior, to concentric triceps surae muscle-strength ratio.
TcGe -	Functional concentric tibialis anterior, to eccentric triceps surae muscle-strength ratio.

In Table 4.14, it can be seen that the only significant difference between injured and uninjured female subjects was for concentric tibialis anterior strength. These results suggest that muscle strength may not be an important risk factor for injuries in runners.

4.5 Identifying underlying relationships

In order to investigate the underlying relationships between variables, a Pearson product-moment correlation was done (separately) for male and female subjects. A summary of all the significant correlations can be found in Addendum F.

In male subjects, the total amount of injuries sustained by runners did not correlate with any of the other variables, but the presence of an injury (injured yes/no) showed a moderately positive correlation with the posterior thigh and lower-back flexibility (sit-and-reach) score. This lends moderate support to the theory that ligamentous laxity may predispose an athlete to injury (Krivickas, 1997:134).

Injured female subjects (injured yes/no), displayed a strong ($r=0.60$) positive correlation with running pace, and moderate positive correlations with concentric tibialis anterior strength ($r=0.52$) and the conventional eccentric hamstrings : quadriceps ratio ($r=0.50$). The total amount of injuries sustained by female runners tended to increase with an increase in running pace ($r=0.52$), concentric tibialis anterior strength ($r=0.55$), the conventional eccentric hamstrings : quadriceps ratio ($r=0.51$) and the functional ratio for knee flexion ($r=0.54$).

4.5.1 Correlations of predictor variables identified for male subjects

In male subjects, a greater degree of forefoot varus was associated with an increase in age (r=0.42), and a decrease in the average concentric hamstrings strength (r=-0.45). Arch index displayed a moderately positive correlation (r=0.44) with the functional leg-length difference, and a high percentage body fat was associated with increases in both weight (r=0.73), and BMI (r=0.78).

As mentioned above, male subjects with increased posterior thigh and lower-back flexibility demonstrated only a moderate positive correlation with the presence of an injury but not with any of the other variables. No significant correlations were found for dynamic hip abductor strength (Trendelenberg sign).

4.5.2 Correlations of predictor variables identified for female subjects

In female subjects, an increased degree of forefoot varus were associated with higher lower-leg strength ratios. A negative correlation was identified between arch index and the degree of passive hip extension, indicating that a decrease in the hip extension range of motion was associated with a higher medial longitudinal arch angle in these subjects.

The longitudinal arch angle was found to correlate negatively with Q-angle (r=-0.74) and age (r=-0.55). This suggests that a larger Q-angle is associated with a lower medial longitudinal arch. Female subjects with a valgus alignment of their knees were generally longer (r=-0.63), and ran on softer surfaces (r=-0.75) than shorter subjects.

A positive correlation was identified between Q-angle and running experience (r=0.54), eccentric tibialis anterior : triceps surae ratio (r=0.59), and the functional ratio for dorsiflexion (r=0.52). Female subjects with smaller Q-angles were found to have stronger eccentric strength of the triceps surae muscles(r=-0.56), and higher medial longitudinal arches (r=-0.74).

A greater amount of functional leg-length differences was present in subjects training on harder surfaces (r=0.53), and a weaker eccentric tibialis anterior : triceps surae strength ratio (r=-0.53).

Apart from the above mentioned correlation of running experience with Q-angle (r=0.54), it was also positively correlated with the concentric tibialis anterior : triceps surae strength (r=0.58), the functional ratio for knee flexion (r=0.50) and the functional ratio for plantarflexion (r=0.55). This may suggest that more optimal functional strength ratios develop with increasing experience, or that only subjects with optimal functional strength ratios continue to run for an extended period of time.

More experienced female runners tended to have less eccentric quadriceps strength (r=-0.64), and less concentric (r=-0.51) and eccentric triceps surae strength(r=-0.53).

4.5.3 Summary of significant correlations between other variables

4.5.3.1 Anatomical alignment measures

In female subjects a faster running pace was associated with weak dynamic hip abductors (r=-0.64). This repeats the observation that injured male subjects tended to have better dynamic hip abductor strength than uninjured subjects. Similar results could not be found in the literature, and could be an indication of sport specific demands placed on runners.

In addition, in female subjects, hip extension displayed strong negative correlations with BMI (r=-0.65), navicular tuberosity height (r=-0.66), and arch index (r=-0.62). It can therefore be deduced that in the present study, female subjects with impaired passive hip extension range of motion tended to have a higher BMI, and higher medial longitudinal arches.

4.5.3.2 Muscle strength characteristics

Few significant correlations were found for muscle-strength measurements, especially in male subjects. In male subjects concentric quadriceps strength tended to decrease with age (r=-0.64) and in female subjects the eccentric hamstrings : quadriceps ratio declined with an increase in running pace (r=-0.60).

4.5.3.3 Anthropometric characteristics

Older male subjects were weaker in concentric contractions of the quadriceps muscle(r=-0.64). They also ran slower (r=-0.70) than younger subjects. Percentage body fat was correlated in both male (r=0.73) and female (r=0.59) subjects to an increase in body weight, and showed a strong positive correlation in male subjects with BMI (r=0.78). As can be expected, a strong positive association was found in male and female subjects between body weight and height, but in male subjects with increased body weight the range of motion for hip extension were lower (r=-0.47).

In female subjects, weight was also negatively correlated with anatomical leg-length discrepancy (r=-0.54). Furthermore, longer female subjects tended to have a higher percentage body fat (r=0.59) and weight (r=0.65).

Higher BMI values were also associated with older runners in male subjects (r=0.77), and decreased hip extension range of motion (r=-0.65) in female subjects.

4.5.3.4 Training parameters

The only training parameters in this study to show significant correlations were the weekly training distance run by female subjects as well as their running pace. The former correlated positively with the concentric hamstrings : quadriceps muscle-strength ratio (r=0.73) indicating a higher concentric ratio with increased weekly training distance. A faster running pace was associated with a decreased eccentric hamstrings : quadriceps muscle-strength ratio (r=-0.60), as well as a decreased functional ratio for knee flexion (r=-0.65).

4.5.4 Summary

Older athletes in the present study ran slower, had weaker muscle strength, weighed more and had a higher percentage of body fat than younger subjects. Interestingly, they did not have a higher incidence of injuries than their younger counterparts.

A set of anatomical alignment measures were identified that could be used to accurately predict injured and uninjured runners. Unfortunately, few significant correlations were found for muscle-strength characteristics and training parameters. An independent t-test also failed to identify significant differences between the muscle-strength characteristics of injured and uninjured subjects. Although the nature of the study was cross-sectional, it appears that anatomical alignment measures may be more important in the prediction of running injuries than muscle-strength characteristics. If this is true, the value of muscle strengthening exercises in the rehabilitation of injured runners should also be re-evaluated.

The observation that injured male runners had stronger dynamic hip abductors was accentuated by the strong negative correlation found between dynamic hip abductor strength and running pace in female subjects. This finding was not reported by other authors, and is difficult to explain. The conclusion can be made that it may be advantageous for runners to have weaker gluteus medius muscles (and subsequently more pelvic motion), for these runners ran faster and had a lower incidence of injuries than subjects with strong dynamic hip abductors.

More research is needed to investigate the questions raised by this study.

5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

To conclude the study on the characteristics of the high risk runner, this chapter will discuss the results obtained with the objectives of the study in mind and draw conclusions on the role played by anatomical alignment and muscle strength in the etiology of running injuries.

This chapter will also consider the limitations of the study and the influence these might have had on the results. Finally, directions for future research sparked by these findings will be recommended with some possible practical implications.

5.2 The role of anatomical alignment and muscle strength in the etiology of running injuries

5.2.1 Introduction

Anatomical malalignment and muscle-strength deficits have been identified in several studies as factors that may predispose athletes to injury (Marti et al., 1988:285). This is especially true of athletes in a sport that has a repetitive nature such as running

(James et al., 1978:40). It has been hypothesized that the key to preventing injury may lie in recognizing and correcting potential problems before they cause injuries (O'Toole, 1992:S360). The main objective of this study therefore was to determine the importance of anatomical alignment in the prediction of injuries in a population of runners. Furthermore, the relationship of muscle strength with the incidence of running injuries was investigated. These investigations were conducted with the objectives in mind that were formulated in Chapter 1. The extent to which these objectives have been reached will now be discussed.

5.2.2 The importance of anatomical-alignment measures in the prediction of running injuries

The anatomical alignment measures that were studied include arch index, forefoot varus, longitudinal arch angle, leg-length discrepancy, posterior thigh and lower-back flexibility, Q-angle, knee varus/ valgus alignment, passive hip extension range of motion, and dynamic hip abductor strength.

For male subjects five variables were identified with the use of a discriminant analysis that could accurately (94 %), predict injuries in runners. This model was also 83 % correct in classifying uninjured male subjects. Four out of these five (4/5) variables were anatomical alignment measures. The identified anatomical alignments were arch index, forefoot varus, posterior thigh and lower-back flexibility (sit-and-reach) and dynamic hip abductor strength (Trendelenberg sign).

In the predictor model for female subjects, eight variables were included of which only one was not an anatomical alignment measure. These variables could predict female runners with an accuracy of 88 % for injured and 100 % for uninjured subjects. Predictor variables in the female model were: arch index, forefoot varus, longitudinal arch angle, functional leg-length discrepancy, knee varus/ valgus alignment, Q-angle, and hip extension range of motion.

The only variables that were repeated in both the male and female predictor models were arch index and forefoot varus.

5.2.3 The relationship of muscle-strength characteristics in the lower extremity with the incidence of running injuries

The following muscle-strength parameters were measured in this study:

- maximal concentric and eccentric strength
- conventional and functional agonist-antagonist strength ratios

Muscle-strength parameters were measured for knee flexion and extension as well as plantar and dorsiflexion of the ankle. The results in this case were somewhat disappointing in that no significant differences were found between injured and uninjured subjects.

This led to the conclusion that inadequate muscle strength or strength imbalances around a joint may not be an important role player in the etiology of running injuries.

5.2.4 The importance of anthropometric characteristics and training parameters in the prediction of running injuries

In the present study, anthropometric characteristics were not found to be of major importance in the prediction of running injuries although the percentage body fat was included with variables identified by the discriminant analysis for male subjects. In female subjects running experience was the only variable included in the discriminant analysis that was not an anatomical alignment measure, but the values for the injured and uninjured female subjects showed that both groups have been regularly participating in running-related activities for between two and three years.

The importance of training parameters and anthropometric characteristics in relation to anatomical alignment in the etiology of running injuries warrants further investigation.

5.2.5 Summary

In conclusion, while anatomical alignment measures were successful in retrospectively predicting injuries in a cohort of runners, no significant relationship between muscle-strength characteristics and injury could be found.

The first hypothesis is therefore accepted, but the second rejected.

5.3 Limitations of the study

This study was limited by its retrospective collection of data and therefore potential selection biases and inability to determine cause and effect. A further limitation was the failure to record an overall measure of foot posture and running shoes.

5.4 Future research

This study was not the first to address the role of anatomical alignment measures in the etiology of running injuries. It seems however, to be the first to document the relationship of muscle strength with running injuries. Suggestions for studies along the same lines include:

- studying a larger population
- conducting the study prospectively
- studying the value of exercise to correct anatomical malalignments
- compiling normative values for muscle strength and strength ratios in runners
- determining the cumulative effect of training errors on injury in runners with an underlying malalignment.

Conclusive results in this regard will go far to explain the relative importance of the various causative factors in the etiology of running injuries.

5.5 Recommendations and practical implications

Recreational and competitive running is a sport practiced by many individuals to improve cardiorespiratory function and general well-being (Macera, 1992:55). Injury however, caused every fifth runner (1/5) in a study by Marti et al. (1988:289) to fully interrupt training, 1 in 7 to seek medical attention and 1 out of every 40 runners to miss work.

This study identified a set of variables that can be used to identify runners who are at risk of sustaining an injury. This may be of great value for medical practitioners and runners alike. The results also indicated that muscle strength, anthropometric characteristics and training parameters may play a smaller role in injury development than expected. More research is needed to establish cause-effect relationships.

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ADDENDUM A

TELEPHONIC SCREENING FOR POSSIBLE PARTICIPANTS

Exclusion criteria:

* A "**YES**," answer to any of the following questions would mean that the athlete may **not** participate in the study.

		YES/NO
1.	Has your doctor ever said that you have a heart condition?	_____
2.	Do you feel pain in your chest when you run or do other physical activities?	_____
3.	Do you have a muscle or joint problem that is made worse by physical activity (e.g. fibromyalgia or arthritis)?	_____
4.	Do you have any other chronic condition or a degenerative illness (e.g. muscular dystrophy)?	_____
5.	Do you use any medication at this time?	_____
	If "YES," please specify: _____	
	_____	
6.	If female, are you pregnant?	_____
7.	Are you aware of any other reason why you should not participate in this study?	_____
	If "YES," please specify: _____	
	_____	
8.	Do you currently have a injury that prevents you from training ?	_____

Inclusion criteria:

* A "**YES**," answer to any of the following questions would mean that the athlete **may** participate in the study.

		YES/NO
1.	Do you run at least 8 km a week?	_____
2.	Have you been participating in running or running related activities for at least one year?	_____
3.	Are you older than 16 years?	_____

ADDENDUM B

PRE-TEST INSTRUCTIONS

Pre-test instructions

1. Please refrain from strenuous physical activity for at least two days before the test.

2. Get an adequate amount of sleep the night before the test.

3. Wear a comfortable, loose fitting T-shirt and running shorts. Female subjects may wear a bikini- or aerobics top for body fat percentage measurements.

ADDENDUM C

INFORMED CONSENT

Informed consent

Dear subject!

This is a research project of the School for Biokinetics, Recreation, and Sportsciences in the Faculty of Health Sciences at the Potchefstroom University for Christian Higher Education.

All information obtained during testing will be treated as privileged and confidential and will be used for research purposes only. Participation in this project is voluntary and you are free to withdraw at any stage.

1. Testing Procedures

You will be required to complete a questionnaire pertaining to your training program and injury history, as well as personal information (e.g. age, surfaces that you train on).

A series of physical tests will be performed to measure your flexibility, anatomic alignment, percentage body fat, as well as body weight and height. Leg strength will also be measured.

2. Risks and Discomforts

You may experience fatigue after the strength test, and muscle stiffness and pain may occur the following day due to the strenuous nature of the testing. Everything possible will be done to minimize adverse consequences.

3. Freedom of Consent

I, the undersigned _____, hereby declare that the information disclosed by me on the questionnaire is true and just. I understand the test procedures that will be performed and the possible risks and discomforts. Any questions that I had in this regard were answered to my satisfaction.

I participate in this study at my own risk and will not hold any of the personnel or students at the Institute of Biokinetics accountable for any discomfort or injury that may occur as result of the testing.

_____ Date _____
Subject

_____ Date _____
Witness

ADDENDUM D

DATA COLLECTION SHEET

BIOKINETICS STUDY: RUNNERS **SUBJECT NUMBER:**

Surname	Initials	Title

Tel. No

Home	Work	Cell.

Marathon Club

QUESTIONNAIRE

Age Group

<19	20-29	30-39	40-49	50-59	>60

Gender

Male	Female

Experience: For how long have you been running regularly?

<1 year	1-2 years	2-3 years	3-5 years	5-10 years	>10 years

Surface: On what type of surface do you run?

Grass	Dirt road	Tar	Cement

What is the distance (km), that you train in a week?

How much time do you spend on stretching?

What is your personal best over 5 km (as measured at a race or official time trial)?

PHYSICAL TESTING

1. ANTHROPOMETRIC MEASUREMENTS

a) Weight Height

b) Body Mass Index

c) Percentage body fat

Subscapula				Umbilicus				
Triceps				Pectoral				

Supra-iliaca				Quadriceps			
Supra-spinal				Gastrocnemius			
Iliocristal				Biceps			
				% Body Fat			

2. ANATOMICAL ALIGNMENT MEASUREMENTS

a) Flexibility

Sit-and-reach (cm)

Hip extension (degrees)

Left	Right

b) Anatomical alignment

Measurement	Value		
	Left	Right	Average
Forefoot varus			
Longitudinal arch angle			
Navicular tuberosity height			
Foot length			
Arch Index			
Q angle			

Knee varus/valgus

Medial femoral epicondylar distance	
Medial malleolar distance	
Con. distance – mall. Distance	

Leg length discrepancy (cm)

	Left	Right	Difference
Anatomical			
Functional			

3. MUSCLE STRENGTH

a) Knee Extension/Flexion

	Left		Right	
	Con	Ecc	Con	Ecc
Quadriceps				
Hamstrings				

b) Ankle Plantarflexion/Dorsiflexion

	Left		Right	
	Con	Ecc	Con	Ecc
Triceps surae				
Tibialis anterior				

ADDENDUM E

PRE-SEASON MEDICAL EXAMINATION

GENERAL EXAMINATION FORM **SUBJECT NO.:** _____

ATHLETE INFORMATION

Name: _____

Surname: _____

Mass	Height	% Body Fat/BM	Blood pressu	Pulse rate	Temperature

ABNORMALITY

If "YES," please specify

CARDIOVASCULAR

Rhythm	Yes		No	
Murmurs	Yes		No	
Other	Yes		No	

_____

_____

RESPIRATORY

Yes		No	

_____

_____

NEUROLOGICAL

Migraine	Yes		No	
Concussion	Yes		No	

_____

_____

MUSCO-SKELETAL

Neck	Yes		No	
Thoracic spine	Yes		No	
Lumbar spine	Yes		No	
Shoulder	Yes		No	
Elbow	Yes		No	
Hip	Yes		No	

Knee	Yes		No	

Ankle	Yes		No	

Foot	Yes		No	

DERMATOLOGICAL

Scars	Yes		No	

Other	Yes		No	

Thyroid	Yes		No	

Lymph nodes	Yes		No	

Urogenital	Yes		No	

MEDICAL FORM

If "YES," please specify.

Do you have a currant injury? (grade)	Yes		No	

Are you on any medication?	Yes		No	

Are you allergic to anything?	Yes		No	

Have you ever been hospitalized for injury or illness?	Yes		No	

Have you ever had any surgery?	Yes		No	

Have you ever suffered from a heart-related illness?	Yes		No	
Is there a history of heart problems in your family?	Yes		No	

Have you ever had any of the following?

Diabetes	Yes		No	
Hepatitis	Yes		No	
Asthma	Yes		No	
Frequent headaches	Yes		No	
Eye injuries	Yes		No	
Stomach ulcers	Yes		No	
Chest pains	Yes		No	
Fainting spells	Yes		No	
Has any one in your family died suddenly before the age	Yes		No	

45?				

Have you ever had seizures/fits?	Yes		No	

Have you ever been knocked out or had concussion?	Yes		No	

Are you prone to getting leg cramps?	Yes		No	

Have you had any immunizations in the last year?	Yes		No	

Do you wear glasses or contact lenses?	Yes		No	

Do you use or wear any special braces or padding wh participating in sport?	Yes		No	

Have you had any fractures (including stress fractures)?	Yes		No	

Are you taking any nutritional or other supplements?	Yes		No	

ADDENDUM F

A SUMMARY OF THE PEARSON PRODUCT-MOMENT CORRELATION FOR MALE AND FEMALE SUBJECTS.

SUMMARY OF THE PEARSON PRODUCT-MOMENT CORRELATION FOR MALE AND FEMALE SUBJECTS.

Gender					
Male			Female		
Variable	**Correlates with**	**Strength of correlation (r)**	**Variable**	**Correlates with**	**Strength of correlation (r)**
Total injuries	-	-	**Total injuries**	Pace TconX HQ ecc HcQe	0.52 0.55 0.51 0.54
Injured yes/no	Sit-&-reach	0.43	**Injured yes/no**	Pace TconX HQ ecc	0.60 0.52 0.50
Muscle Strength:			**Muscle Strength:**		
QconX	Age	-0.64	**QconX**	FlexTr Sit-&-reach Height	0.55 0.54 0.53
QeccX	Age	-0.48	**QeccX**	Experience Sit-&-reach	-0.64 0.51
HconX	Age Surface F. Varus	-0.45 -0.51 -0.45	**HconX**	FlexTr	0.51
HeccX	Age	0.41	**HeccX**	Age Sit-&-reach	-0.51 0.53
GconX	Experience Q-angle	-0.49 -0.50	**GconX**	Experience	-0.51
GeccX	DistWk	-0.41	**GeccX**	Experience Q-angle	0.63 -0.56
TconX	-	-	**TconX**	-	-
TeccX	Hip ext. Footlength Knee v/v	-0.51 0.54 0.43	**TeccX**	Q-angle LLD (F)	0.59 -0.53
HQ con	-	-	**HQ con**	Footlength	0.63
HQ ecc	-	-	**HQ ecc**	Pace	-0.60
TG con	Q-angle	0.53	**TG con**	Experience F. Varus	0.58 0.57
TG ecc	Age Hip ext.	-0.44 -0.52	**TG ecc**	F. Varus	0.52
HeQc	Hip ext.	-0.43			
HcQe	Hip ext. Knee v/v	-0.45 -0.43	**HcQe**	Pace Experience	-0.60 0.50
TeGc	Q-angle Knee v/v	0.49 0.47	**TeGc**	Experience F. Varus	0.55 0.67
TcGe	Age	0.42	**TcGe**	F. Varus Q-angle	0.50 0.52

Gender					
Male			Female		
Variable	**Correlates with**	**Strength of correlation (r)**	**Variable**	**Correlates with**	**Strength of correlation (r)**
Anatomical alignment measures:			**Anatomical Alignment Measures:**		
Trend.	-	-	**Trend.**	Pace	-0.64
Sit-&-reach	-	-	**Sit-&-reach**	QconX	0.54
				QeccX	0.51
				HeccX	0.53
Hip ext.	BMI	-0.41	**Hip ext.**	BMI	-0.65
	Weight	-0.47		NTH	-0.66
	Footlength	-0.46		AI	-0.62
	TeccX	-0.51			
	TG ecc	-0.52			
	HeQc	-0.43			
	HcQe	-0.45			
F. Varus	Age	0.42	**F. Varus**	TG con	0.57
	HconX	-0.45		TG ecc	0.52
				TeGc	0.67
				TcGe	0.50
LAA	LLD (F)	0.57	**LAA**	Q-angle	-0.74
				Age	-0.55
Footlength	Height	0.46	**Footlength**	Age	0.55
	Hip ext.	-0.46		DistWk	0.53
	TeccX	0.54		AI	0.96
				LLD (A)	-0.56
				HQ con	0.63
NTH	AI	0.88	**NTH**	AI	0.96
	LLD (F)	0.47		Hip ext.	-0.66
AI	NTH	0.88	**AI**	NTH	0.96
	LLD (F)	0.44		Hip ext.	-0.62
Q-angle	GconX	-0.50	**Q-angle**	Experience	0.54
	TG con	0.55		LAA	-0.74
	TeGc	0.49		GeccX	-0.56
				TG ecc	0.59
				TcGe	0.52
Knee v/v	FlexTr	0.44	**Knee v/v**	Surface	-0.75
	TeccX	0.43		Height	-0.63
	HcQe	-0.43			
	TeGc	0.47			
LLD (A)	BMI	0.44	**LLD (A)**	Age	-0.51
				FlexTr	0.58
				Weight	-0.54
				Footlength	-0.56
LLD (F)	LAA	0.57	**LLD (F)**	Surface	0.53
	NTH	0.47		TG ecc	-0.53
	AI	0.44			

Gender					
Male			Female		
Variable	**Correlates with**	**Strength of correlation (r)**	**Variable**	**Correlates with**	**Strength of correlation (r)**
Other:			**Other:**		
Age	Pace	0.70	**Age**	Pace	0.54
	HeccX	-0.41		HeccX	-0.51
	BMI	0.41		Surface	-0.44
	F. Varus	0.42		LAA	-0.55
	QconX	-0.64		Footlength	0.55
	HconX	-0.45		LLD (A)	-0.51
	QeccX	-0.48			
	TG ecc	0.44			
	TcGe	0.42			
DistWk	GeccX	-0.41	**DistWk**	Footlength	0.53
				HQ con	0.73
Surface	HconX	-0.51	**Surface**	Knee v/v	-0.75
				LLD (F)	0.53
FlexTr	% Fat	-0.45	**FlexTr**	LLD (A)	0.58
				QconX	0.55
				HconX	0.51
Pace	Age	0.70	**Pace**	Age	0.54
	Weight	0.43		Trend.	-0.64
	BMI	0.50		HQ ecc	-0.60
				HcQe	-0.60
Experience	GconX	-0.49	**Experience**	GconX	-0.51
				Q-angle	0.54
				QeccX	-0.64
				GeccX	-0.53
				TG con	0.58
				HcQe	0.50
				TeGc	0.55
% Fat	FlexTr	-0.45	**% Fat**	Weight	0.59
	Weight	0.73			
	BMI	0.78			
Weight	% Fat	0.73	**Weight**	% Fat	0.59
	Height	0.54		Height	0.65
	BMI	0.77		BMI	0.64
	Pace	0.43		Footlength	0.50
	Hip ext.	-0.47		LLD (A)	-0.54
Height	Weight	0.54	**Height**	Weight	0.65
	Footlength	0.46		Footlength	0.51
				Knee v/v	-0.63
				GconX	0.53
BMI	Weight	0.77	**BMI**	Weight	0.64
	Hip ext.	-0.41		Hip ext.	-0.65
	Age	0.77			
	Pace	0.50			
	% Fat	0.78			
	LLD (A)	0.44			

* The correlations of muscle strength values with other muscle strength values were not included in this summary.

QconX - Average concentric quadriceps strength.
QeccX - Average eccentric quadriceps strength.
HconX - Average concentric hamstrings strength.
HeccX - Average eccentric hamstrings strength.
GconX - Average concentric triceps surae strength.
GeccX - Average eccentric triceps surae strength.
TconX - Average concentric tibialis anterior strength.
TeccX - Average eccentric tibialis anterior strength.
HQ con - Conventional concentric, hamstrings to quadriceps muscle-strength ratio.
HQ ecc - Conventional eccentric, hamstrings to quadriceps muscle-strength ratio.
TG con - Conventional concentric, tibialis anterior to triceps surae muscle-strength ratio.
TG ecc - Conventional eccentric, tibialis anterior to triceps surae muscle-strength ratio.
HeQc- Functional eccentric hamstrings, to concentric quadriceps muscle-strength ratio.