



Ghent University

Department of Rehabilitation Sciences and Physiotherapy

INTRINSIC RISK FACTORS FOR SPORTS INJURIES TO THE LOWER LEG AND ANKLE

Tine Willems

Thesis submitted in fulfilment of the requirements for the degree of
Doctor in Motor Rehabilitation and Physiotherapy

Ghent 2004

Promotor:

Prof. dr. E. Witvrouw

Co-promotor:

Prof. dr. D. De Clercq

Examination Board:

Prof. dr. I. De Bourdeaudhuij

Prof. dr. D. De Clercq

dr. M. Lake (John Moores University of Liverpool, UK)

Prof. dr. M. Lenoir

Prof. dr. P. Roosen (Arteveldehogeschool Gent)

Prof. dr. P. Vaes (Vrije Universiteit Brussel)

Prof. dr. G. Vanderstraeten

Prof. dr. W. van Mechelen (Vrije Universiteit Amsterdam, NL)

Prof. dr. E. Witvrouw

Process supervisory board:

Prof. dr. I. De Bourdeaudhuij

Prof. dr. D. De Clercq

Prof. dr. R. Philippaerts

Prof. dr. G. Vanderstraeten

Prof. dr. E. Witvrouw

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ACKNOWLEDGEMENTS

During the past four years, I had the pleasure to work with numerous people without whose invaluable help, this thesis would not have been possible.

In addition, this investigation would not have been possible without the substantial funding for equipment, data collection and analysis. This research was supported by a BOF grant (Bijzonder Onderzoeks Fonds) of the Ghent University.

This project was only possible thanks to my promotor and co-promotors, who were willing to give me this opportunity to fulfil my PhD. First of all, I would like to thank my promotor, **Professor Erik Witvrouw**, who was the initiator of this project. His scientific background in risk factor studies, his confidence in my capabilities, his encouraging words in bad days and his enthusiasm in happy days motivated me to finish this project. Thanks for all the opportunities you gave me and your trust in me. I also like to thank **Professor Dirk De Clercq** for his scientific and critical view on the biomechanical aspects of this project. Our discussions were always very instructive and inspiring for me. You saw things from different perspectives and taught me to question everything. Thanks for your insightful suggestions. Thanks go to **Professor Guy Vanderstraeten** for his constructive advice and criticism and for being the chairman of my doctoral examination. I would also like to thank **Professor Ilse De Bourdeaudhuij** for her statistical advice and **Professor Renaat Philippaerts** for his assistance in collecting and interpreting the anthropometrical and physical characteristics. I thank all the members of my doctoral committee for reading and correcting this doctoral dissertation and the scientific papers it contains.

I gratefully acknowledge the external members of the Examination Board, **dr. Mark Lake**, **Professor Matthieu Lenoir**, **Professor Philip Roosen**, **Professor Peter Vaes** and **Professor Willem van Mechelen** whose constructive remarks contributed to the improvement of this dissertation.

Many thanks go to **Dr. Jan Verstuyft**, who traveled every week to the Department of Movement and Sports Sciences, where many students visited him for their injuries. I also like to thank the **Centre of Sports Medicine** of the University Hospital and **RsScan© International** for allowing me to use their equipment for my investigations.

I would like to thank **Kim, Nele, Fabienne, Anneleen, Friso, Pierre, Jan**, and all the **licentiates Motor Rehabilitation and Physiotherapy** and **licentiates Movement and Sports Sciences**, who helped me in the acquisition and analysis of the data.

Kim and Elke, many thanks as ‘bureau buddies’ for your friendship and listening to me in difficult moments.

Warm thanks go to all my colleagues of the Department of Rehabilitation Sciences and Physiotherapy: **Erik, Dirk, Lieven, Guy, Ann, Kim, Elke, Barbara, Veerle, Pascal, Kathy, Sophie, Bart, James, Els, Koen, Patrick, Fabienne, Bruno, Katleen, Barbara, Kathleen, Bibi, Helga, Stefaan, John, Martine, Hilde, Marc, Wim, Carine, Mieke, Kurt, Wiene, Bert, Els**. I had a great time at the department during the past four years. There was always somebody to change thoughts with, have some fun with or to go sporting with.

I also like to thank my colleagues of the Department of Movement and Sports Sciences, and especially those of the second floor: **Dirk, Anneleen, Jos, Liesbet, Veerle and Pierre**, thank you for your support and the great time we had together.

This project could not have existed without the voluntary cooperation of all the **physical education students**, who I gratefully acknowledge.

I finally like to thank my **family and friends**. Although that you were not physically involved in this project, I like to thank you for your mental support. Thanks for your companionship and for the enjoyable moments that we shared.

I specially like to thank **my parents**. Without your love, trust, care, support and education, I would never have been able to fulfill this PhD. Thanks for giving me all these facilities in my life.

And ‘last but not least’, I would like to thank **Tim**. Thanks for your love, friendship and your patience, and for the everlasting support in which ever choice I made.

To everybody, thank you very much!

Tine Willems

Ghent, 20th December 2004

*Never regard your study as a duty, but as the enviable opportunity to learn
to know the liberating influence of beauty in the realm of the spirit
for your own personal joy and to the profit of the community
to which your later work belongs*
(Albert Einstein)

CHAPTER 1

GENERAL INTRODUCTION

GENERAL INTRODUCTION

Since the eighties, the approach to ankle injuries has undergone a significant change for physical therapists.¹⁵ Before, research on ankle injuries seemed less exciting than research on injuries to the knee or shoulder. This may have been the result of fewer opportunities for dramatic surgical improvements or perhaps little sense that serious disabilities occur as a result of injuries to these areas.²⁴ However, to date, more and more physical therapists now are looking at the foot from a biomechanical focus, recognizing its marvellous functional adaptability and realizing the tremendous stresses put on it every day.¹⁵

Reasons to participate in sports and physical activity are many, such as pleasure and relaxation, competition, socialisation, maintenance, and improvement of fitness and health.³ Regular physical activity reduces the risk of premature mortality in general, and of coronary heart disease, hypertension, colon cancer, obesity, and diabetes mellitus in particular.^{22,54} However, the increasing promotion of physically active lifestyles for their positive effect on physical and mental health^{34,54} brings along the possible problem of increasing the risk of sports injuries, which may in some cases lead to permanent disability.^{2,3} Conn et al.¹³ estimated that there are 26 sports and recreational injury episodes per 1000 persons per year in the US. Due to sports injuries, 20% of schoolchildren and 28% of working adults are absent at least one day a year from school or work respectively. Scandinavian studies document that sports injuries constitute for 10-19% of all acute injuries seen in an emergency room.^{16,36,76} Consequently, sports injuries are a significant cause for concern – for athletes, sports and society.²

Foot and ankle injuries are extremely common in sports.²⁴ Strenuous running, jumping and cutting manoeuvres are associated with the most popular sports. Therefore, it is not very surprising that the majority of sports injuries involve the lower extremity. Ankle sprains are probably the single most common traumatic injury in sports, accounting for 40% of all athletic injuries, especially in soccer, basketball, volleyball, handball, cross-country running, dance and ballet.^{4,24}

Approximately 50% of all sports injuries are secondary to overuse. These injuries result from repetitive microtraumata that cause local tissue damage.⁷² The most common overuse injuries in athletes are Achilles tendinopathy and medial tibial stress syndrome.³⁰

Most of the sports injuries require medical care and rehabilitation. After injury, it is important for an athlete to be able to return to sport as soon as possible and at the highest level of functioning. However, treating sports injuries is often difficult, expensive and time-consuming.⁵³ Understanding the injury as well as the role of risk factors associated with injuries is important in planning and carrying out prevention and treatment of these injuries.⁵⁸ In view of the high frequency of injury, not only during leisure time activities but also in professional sports, it is clear that analyses of risk factors for sports injuries are urgently required.³²

Many sports injuries are the result of unavoidable accidents, but there are also many others that could be prevented.⁵³ Prevention of injury is a major goal of sports medicine practitioners. To prevent injury there must be a clear understanding of the aetiology. This includes information on why a particular athlete may be at risk in a given situation (risk factors) or how injuries happen (injury mechanism). In addition, measurement of the outcome (injury) must include a standardised definition of the injury, as well as a systematic method of collecting the information. Valid and reliable measurement of the exposure includes exact information about the population at risk and exposure time.⁵³

1. Causation of sports injuries – A multifactorial model

1.1. Definition of cause

Cause has been defined by Hanks²⁵ as ‘a person, thing, event, state or action that produces an effect’. In medical sciences, cause is also often referred to as ‘aetiology’, ‘pathogenesis’, or ‘mechanisms’.²³ Further, Last³⁵ defined *causality* epidemiologically as ‘the relating of causes to the effects they produce’. This latter definition focuses on the process of establishing causality.⁴⁴

1.2. Assessing causal association

Before an assessment of causation can be made, the effect of a given factor must be examined in all individuals exposed to the possibility of injury. Stating that a risk factor is a cause of an injury is much different from merely observing an association. Although an association must exist between a factor and an injury for that factor to be a cause, the converse is not necessarily true.⁴⁴

In most areas of medicine, a disease or injury is associated with multiple causative factors (multifactorial in aetiology), and each of these factors may be associated with many diseases or injuries. It has been suggested that myriad factors may contribute to the development of a disease or injury, and that each factor is 'itself the result of a complex genealogy of antecedents'.⁴⁰

In multifactorial diseases or injuries, a variety of terms may be applied to each causal factor or group of factors, depending on the role that each plays. A factor is considered to be a necessary cause when it must always precede an effect.³⁵ That is, a given effect or outcome (or injury) can not occur without the presence of the necessary factor. If a constellation of factors produces an outcome, the minimum set of factors required to produce that outcome are referred to as a sufficient cause. A given factor may be necessary, sufficient, both, or neither.³⁵

1.3. A model of multifactorial aetiology in athletic injury

Sports injuries are multi risk phenomena with various risk factors interacting at a given time.⁴⁴ Risk factors are traditionally divided into two main categories: intrinsic (or internal) and extrinsic (or external) risk factors.^{37,65,68,73}

The intrinsic risk factors are related to the individual biological or psychosocial characteristics, such as age, joint instability, muscle strength, muscle tightness, biomechanics, conditioning, previous injuries, adequacy of rehabilitation, psychosocial stress, etc.

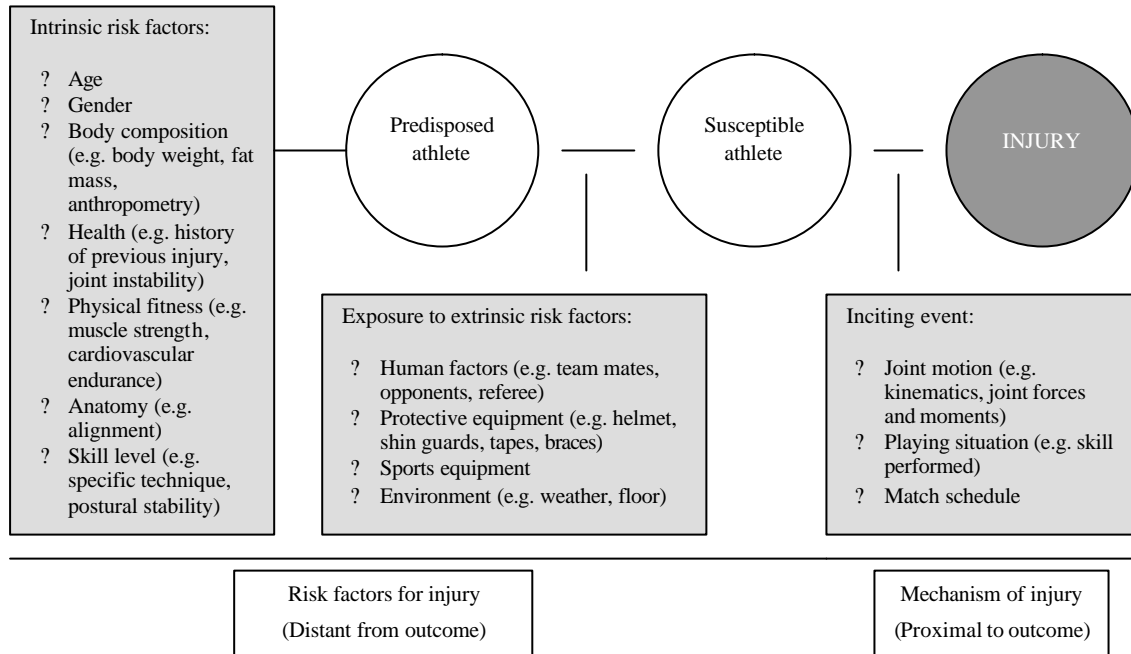
Extrinsic risk factors relate to environmental variables, for example, level of play, exercise load (type, intensity and amount of physical activity), position played, equipment such as shin guards, taping, and shoes, weather conditions, playing field conditions, rules, and foul play. Both intrinsic and extrinsic factors can partially influence each other and are therefore not independent of each other.

Risk factors can also be divided into modifiable and non-modifiable factors. Although non-modifiable risk factors such as gender and age may be of interest, at least, it is important to study factors which are potentially modifiable through physical training or behavioural approaches, such as strength, balance, or flexibility.²

Studies on the aetiology of sports injuries require a dynamic model that accounts for the multifactorial nature of sports injuries. One such dynamic model is described by

Meeuwisse.⁴⁴ This model describes how multiple factors interact to produce an injury (Figure 1).

Figure 1. A dynamic, multifactorial model of sports injury aetiology (adapted from Meeuwisse⁴⁴)



It can be seen in the model that numerous intrinsic risk factors may predispose an individual to injury. Although predisposing factors may be necessary, they are rarely sufficient to cause injury.³⁵

In this theoretical model, the extrinsic risk factors act on the predisposed athlete from outside. Such factors are enabling factors in that they facilitate the manifestation of injury.³⁵ It is the presence of both intrinsic and extrinsic factors that renders the athlete susceptible to injury, but the mere presence of these factors is usually not sufficient to produce injury. It is rather the sum of these factors and the interaction between them that ‘prepares’ the athlete for an injury to occur in a given situation.⁴⁴

Meeuwisse⁴⁴ describes the inciting event as the final link in the chain that causes an injury. These precipitating factors are associated with the onset of the injury and are almost always regarded as necessary causes.³⁵

The sports medicine practitioner typically focuses on these inciting events and the mechanism of injury itself. However, little attention tends to be paid to the other factors that are distant from the outcome and precede the inciting event. There are likely many

intrinsic risk factors that predispose the athlete and enabling factors that increase the susceptibility to injury.⁴⁴

1.4. Study design

Different kinds of study design exist in injury epidemiological research. These include case-control studies and cohort studies. In a case control study design, the approach is to compare the frequency or level of potential risk factors between a group of injured athletes and a comparable group of injury-free athletes. Often, information on risk factors is collected retrospectively, because the approach is to identify persons with an injury of interest and then look backward in time to identify factors that may have caused it.

In a cohort study, all data are collected in a standardised manner prospectively in time. The approach involves measuring potential risk factors before injuries occur, after which new cases and exposure are reported during a period of follow up.² Prospective cohort study designs have great applicability to the study of sports and recreational injury because cohorts can be assembled and data on putative risk factors can be obtained at the start of the sports season.⁷⁰ Athletes can then be followed over the course of the season and injuries can prospectively be identified by their health care providers. The time between acquisition of risk factor data and ascertainment of injuries should be noted. Acquisition of accurate data on participation in sports (so-called 'exposure' data) is critical to success of these studies.²⁶

The prospective cohort study design is a more preferable study design compared to the case control study design, because one of the problems of retrospective investigations is that of determining whether the findings are a result or a cause of the subject's injury. Only longitudinal prospective studies can determine causative relationships.²⁶ However, the main disadvantage of the cohort study design is that study size is critical, as it may be necessary to include and monitor a large number of athletes for an exceedingly long study period, particularly for less common injury types.²

2. Application of the model

2.1. Definition of injury

When conducting and interpreting epidemiologic sports injury studies, one is confronted with the methodologic issue of the definition of sports injury. In general 'sports injury' is a

collective name for all types of damage that can occur in relation to sporting activities. Various studies define the term 'sports injury' in different ways.³ The most common criterion for the definition of an injury is an absence from training or game(s) followed by the need for medical treatment and the diagnosis of anatomic tissue damage.¹⁷ This criterion, however, can be misleading and is open to misinterpretation. Absence from training and games is not only influenced by a very strong subjective component but is also directly affected by the frequency of games, the availability of medical treatment and, finally factors such as the importance of the player and the expected outcome of the game.³² In some studies, sports injuries are recorded based on insurance company records, which implies that the injured player was treated by a physician or in a hospital.^{57,59} The different definitions of 'sports injury' partly explain the different incidences found in investigations. If sports injuries are recorded through medical consultations, this system probably leads to an underestimation of the incidence of less severe injuries or symptoms due to overuse, which are not always subject to medical treatment. The medical diagnosis may seem to be an objective criterion, but it is also directly related to the availability of qualified physicians.^{32,68}

To make sports injury surveys comparable, an unambiguous, universally applicable definition of 'sports injury' is the first prerequisite. This definition should be based on a concept of health other than that customary in standard medicine. An example of an extensive definition that takes these considerations into account is the one proposed by the Council of Europe,^{32,68} in which a sports injury is defined as any injury as a result of participation in sport with one or more of the following consequences: 1) a reduction in the amount or level of sports activity; 2) a need for (medical) advice or treatment or 3) adverse social or economic effects.¹⁴

2.2. *Acute and overuse injuries*

There are two broad categories of athletic injuries, which differ markedly in their aetiology. First, acute injuries are those associated with a macro-traumatic inciting event. The inciting event is readily identified by the application of some external force with resultant tissue disruption. In overuse injuries, the inciting event is often less apparent, and the resultant tissue damage is due more to overstress than to acute disruption. Meeuwisse⁴⁴ believes that the relative contribution of intrinsic and extrinsic risk factors differs for these two types of injury. In overuse injuries, there is likely a greater contribution from intrinsic

risk factors. With acute injuries, the relative contribution of factors that constitute a nearly sufficient constellation is often less clear.⁴⁴

2.3. Risk factors

Extrinsic risk factors

The majority of investigations on risk factors for injury have been carried out on extrinsic risk factors.⁵⁰ Murphy et al.⁴⁹ revealed that there is some agreement about the extrinsic risk factors for injuries of the lower leg and ankle. By far the biggest determinant of injury risk in sports is the nature of the activity itself. Contact sports carry the greatest risk of ankle sprains of which soccer is the number one. After soccer, other team sports such as handball, volleyball, and basketball also cause a significant proportion of ankle injuries.^{3,63} For exercise-related lower leg injuries, running and jogging are the main risk sports.⁶⁵ There is a general agreement among researchers that injury incidence is greater during competition than during training sessions.^{18,21,46,51,56,60,61} Environmental conditions, such as terrain, climate and correct equipment, also play a major role in the outcome of an injury.⁶⁵

Intrinsic risk factors

In the literature, there are very few prospective studies focusing on identifying risk factors for sports injuries of the ankle and there are even less on injuries of the lower leg. There is some agreement among authors with regard to few intrinsic risk factors; however, considerable controversy remains.^{10,49} One of the most important and well-established intrinsic risk factors for future injury of the lower extremity is a history of an injury and inadequate rehabilitation.^{1,19,41} Injuries of the lower leg and ankle have been shown to be more common in athletes with a previous injury.^{1,19,20,39,48,51} For all other prospectively investigated intrinsic risk factors for injuries of the lower extremity, there is a lack of consensus. On the effect of age, risk factor studies have yielded contradictory results. Several studies showed an increased incidence of injury in older athletes,^{33,52,64} others found an increased incidence of injury in younger athletes^{55,43} and others found no association between age and injury.^{9,12,61} The relation between gender and lower extremity injury is also unclear. Some researchers found the female athlete to be at increased risk,^{28,33,75} others found no relationship.^{9,11,71} There are several studies which show an association between measure of aerobic fitness and injury,^{12,27,31,33} although some found no association.^{47,52} Body size has also been implicated as an injury risk factor.^{31,47} Conversely,

some studies have reported no association.^{9,33,43,71} The relationship between limb dominance and injury also remains unclear, as some studies reported an association,^{12,19} and others did not.^{11,60} The literature is also divided about the relationship between flexibility and alignment and injury.⁴⁹ Several studies have shown muscle strength or imbalance to be risk factors for injury,^{7,19,61} however, other studies showed no association.^{11,47,52} Also with regard to the relationship between postural control and injury, there is no consensus. Some studies found an association between diminished balance and injury,^{42,61,67} others found no association.^{11,27}

Retrospective studies showed an association between an increased pronation and exercise-related lower leg pain.^{45,69} In clinical practise, it is frequently assumed that exercise-related lower leg pain is caused by an increased pronation. However, hitherto, no prospective studies have been performed on the dynamical gait related risk factors for exercise-related lower leg pain.

Although that muscle model driven computer simulations showed that an increased touchdown plantar flexion is associated with an increased occurrence of ankle sprains⁷⁴, no prospective studies have investigated the relationship between gait and ankle sprains in vivo.

In conclusion, at present there is little agreement about intrinsic risk factors for sports injuries of the lower leg and ankle. This can probably be explained by differences in subjects who were examined, differences in materials and methods and the overall definition of lower-extremity injury in stead of focussing on one specific injury. In addition, difficulties in prospective studies can contribute to the small number of investigations, since the population size needs to be large enough to compose an injury group. The lack of prospective biomechanical investigations can probably be attributed to the time-consuming and expensive dynamical gait analyses, which are therefore not easy to perform in large populations.

3. Background and aim of this project

Literature reviews on risk factors for lower extremity injuries demonstrated that our understanding of injury causation is limited.^{5,10,29,37,38,49,50,65} Therefore, our aim was to gain a better insight in the intrinsic risk factors for sports injuries of the lower leg and ankle. Because the most common injuries in the studied population were ankle inversion sprains

and exercise-related lower leg pain, we focused this doctoral dissertation on the intrinsic risk factors in the aetiology of these injuries.

Aim 1: To gain a better insight into the intrinsic risk factors for inversion ankle sprains (Chapter 2-3-4-5)

Lateral ankle sprain is an extremely common athletic injury.²⁴ Although ankle sprains are frequently encountered in the sports injury clinic, the causes of this injury remain enigmatic. Beynnon et al.¹⁰ revealed that investigations on extrinsic risk factors for ankle sprains arrived at some agreements, but at this point there is little consensus with regard to the intrinsic risk factors. Based on a review of the literature, the following intrinsic risk factors have previously been investigated: previous sprain; sex; height and weight; limb dominance; anatomic foot type and foot size; generalized joint laxity; anatomic alignment, ankle-joint laxity and range of motion of the ankle-foot complex; muscle strength; muscle reaction time; and postural control.¹⁰ However, there is little evidence in the literature with regard to the contribution of these intrinsic risk factors in the aetiology of ankle sprains derived from well-controlled, prospective investigations. Most proposed risk factors for lateral ankle sprains remain controversial and require further investigation.¹⁰ Therefore, the first purpose of this project was to identify intrinsic risk factors for inversion ankle sprains. In *chapter 2* we retrospectively investigated if deficits in ankle muscle strength and proprioception exist in subjects with a history of ankle sprains. In *chapter 3 and 4*, a comprehensive, prospective investigation of intrinsic risk factors was performed for inversion sprains in physically active male (*chapter 3*) and female subjects (*chapter 4*). The factors examined included anthropometrical characteristics, functional motor performances, ankle joint position sense, ankle muscle strength, lower leg alignment, postural control, and muscle reaction time. In *chapter 5*, the gait related risk factors for inversion ankle sprains were assessed.

Aim 2: To gain a better insight into the intrinsic risk factors for exercise-related lower leg pain (Chapter 6).

Exercise-related lower leg pain is a common and enigmatic overuse problem in athletes and military populations.⁸ In the literature, several aetiological factors have been suggested

to contribute to exercise-related lower leg pain. These proposed factors include in isolation or in combination, changes in training, activity type, volume, intensity and frequency, footwear, and terrain as extrinsic (environmental related) risk factors.^{6,8} As intrinsic risk factors, lack of running experience, poor physical condition, previous injury, decreased muscle strength, muscle fatigue, inflexibility, malalignment and adverse biomechanics have been quoted.^{6,8,66} However, the most quoted and probably the strongest contributing factor is an adverse biomechanical running pattern. Retrospective studies have noted excessive dynamic foot pronation in subjects with a history of exercise-related lower leg pain.^{45,69} In addition, static foot posture in subjects with exercise-related lower leg pain showed pronated foot alignment.^{62,75} However, there is a lack of prospective data with regard to the contribution of adverse biomechanics. Therefore, the second purpose of this project (*chapter 6*) was to perform a prospective investigation of the gait related risk factors for exercise-related lower leg pain.

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CHAPTER 2

PROPRIOCEPTION AND MUSCLE STRENGTH IN SUBJECTS WITH A HISTORY OF ANKLE SPRAINS AND CHRONIC INSTABILITY

**Tine M. Willems¹ PT, Erik Witvrouw¹ PT PhD, Jan Verstruyft² MD,
Peter Vaes³ PT PhD, Dirk De Clercq⁴ PE PhD**

¹ Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, Ghent University, Belgium

² University Hospital Ghent, Belgium, Department of Sports Medicine

³ Department of Physical Education & Physical Therapy, Faculty of Medicine, Brussels University, Belgium

⁴ Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, Belgium

ABSTRACT

Objective: To examine if patients with chronic ankle instability or a history of ankle sprains without chronic instability have worse proprioception or less invertor and evertor muscle strength.

Design and Setting: We assessed proprioception and muscle strength on the Biodex isokinetic dynamometer in the laboratory of the Department of Sports Medicine, University Hospital Ghent.

Subjects: Subjects included 87 physical education students (44 men, 43 women, age = 18.33 ± 1.25 years, mass = 66.09 ± 8.11 kg, height = 174.11 ± 8.57 cm) at the University of Ghent in Belgium. Their ankles were divided into 4 groups: a symptom-free control group, subjects with chronic ankle instability, subjects who had sustained an ankle sprain in the last 2 years without instability, and subjects who sustained an ankle sprain 3 to 5 years earlier without instability.

Measurements: Active and passive joint-position sense was assessed at the ankle, and isokinetic peak torque was determined for concentric and eccentric eversion and inversion movements at the ankle.

Results: Statistical analysis indicated significantly less accurate active position sense for the instability group compared with the control group at a position close to the maximal inversion. The instability group also showed a significantly lower relative eversion muscle strength (% body weight). No significant differences were observed between the control group and the groups with past sprains without instability.

Conclusion: We suggest that the possible cause of chronic ankle instability is a combination of diminished proprioception and evertor muscle weakness. Therefore, we emphasize proprioception and strength training in the rehabilitation program for ankle instability.

Key Words: joint position sense, isokinetic strength, ankle injury, rehabilitation

INTRODUCTION

Lateral ankle sprain is an extremely common athletic injury. Despite extensive clinical and basic science research, the recurrence rate remains high and the reasons why sprains tend to recur stays unclear; thus, successful rehabilitation is difficult.¹ In a review of the potential causes of functional ankle instability, Hertel² cited joint position-sense deficits, muscle-strength deficits, delayed peroneal muscle-reaction time, balance deficits, altered common peroneal nerve function, and decreased dorsiflexion range of motion. However, it remains important to search for the contributory factors of chronic ankle instability (CAI), which is hypothesized to predispose individuals to reinjury after lateral ankle sprains.

Freeman et al.³ proposed that ankle injury may disrupt joint afferents located in the supporting ligaments. After injury to the nervous and musculotendinous tissue, proprioceptive deficits are likely to occur and may manifest as reduced joint position sense. The ability to detect motion in the foot and to make postural adjustments in response to these detected motions is thought to be crucial in the prevention of ankle injury. Similarly, the ability of an individual to detect the position of the foot before foot contact is important. Several authors⁴⁻⁸ have suggested that inversion ankle sprains may occur due to the improper positioning of the foot just before and at foot contact. Improper positioning may be due to the loss of proprioceptive input from mechanoreceptors.

Joint position sense is a component of proprioception and is often measured to assess proprioception. Studies of joint position sense in the chronically unstable ankle have demonstrated varying results.⁹⁻¹¹ Glencross and Tornton⁹ reported a decrease in active joint position sense of the chronically unstable ankle over that of the uninjured ankle. Gross¹⁰ and Holme et al,¹¹ however, failed to reveal any significant differences between injured and uninjured ankles in either active or passive joint position sense.

The evertor muscles are often suggested to play an important role in preventing ligamentous injuries. The strength of the peroneus longus and brevis muscles is supposed to provide support to the lateral ligaments.⁴ Bosien et al¹² and Staples¹³ were the first to measure peroneal muscle strength, but they used manual methods to detect peroneal muscle weakness and found long-term evertor muscle weakness after inversion sprains. Tropp¹⁴ was the first to measure muscle torque at the ankle with an isokinetic dynamometer. His results confirmed an earlier theory that peroneal muscle weakness is a component of CAI. He suggested that the muscular impairment is due to inadequate

rehabilitation and secondary muscle atrophy. Baumhauer et al¹⁵ even found in a prospective study that individuals with a muscle-strength imbalance exhibited a higher incidence of inversion ankle sprains. Conversely, Lentell et al¹⁶ found no significant differences in muscle strength, either isometrically or isokinetically, between the chronically unstable ankles and the uninvolved ankles, suggesting that muscular weakness is not a major contributing factor to the chronically unstable ankle.

We are not aware of any previous investigators who have examined muscle strength and joint position sense in subjects who sustained a sprain in which instability was not a factor. The most common risk factor for ankle sprains in sports is a history of a previous sprain¹⁷; therefore, we think it is important to search for proprioception or muscle-strength deficits in subjects with a history of previous sprains who do not report CAI to learn if these subjects are still at risk for sustaining sprains. Also, we would like to know if the risk for sustaining a sprain is higher for subjects who suffered sprains 1 or 2 years ago compared with subjects who had a sprain more than 2 years ago.

In addition, few researchers have examined eccentric muscle strength. Most researchers have measured isometric or concentric muscle strength in subjects with CAI, although the evertor muscle must contract eccentrically to resist an ankle inversion sprain. Therefore, our purpose was to search for deficits in ankle proprioception and invertor and evertor concentric and eccentric muscle strength in subjects with CAI and a history of ankle sprains.

METHODS

Subjects

Subjects included 87 physical education students (44 men, 43 women; age range, 17-26 years; mean age, 18.33 ± 1.25 years) who were freshman in 2000-2001 at the University of Ghent, Belgium (Table 1). Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Based on these histories, we divided the ankles into 4 groups. Of the 174 ankles (both ankles of 87 subjects), 106 served as control group (group 1). The 53 subjects (29 men, 24 women) in this control group had no prior history of injury to either ankle. The instability group (group 2) consisted of 14 chronically unstable ankles of 10 subjects (4 men, 6 women) who had a history of more than 3 inversion sprains of the same ankle, frequent giving-way episodes, and some complaints of

pain during heavy and intense loading. Four subjects in this instability group complained of bilateral CAI. No subjects in the instability group had suffered severe injury to the unstable ankle for at least 3 months before testing. Group 3 consisted of 20 ankles of 16 subjects (8 men, 8 women) who had sustained 1 to 3 inversion sprains in the previous 2 years but did not complain of instability or other symptoms. Four persons in this group had inversion sprains of both ankles in the same period. Group 4 consisted of 8 ankles in 8 subjects (3 men, 5 women) who had sustained 1 to 3 inversion sprains 3 to 5 years before testing and did not complain of instability or other symptoms. Mechanical instability of the subjects' ankles was not measured. Each volunteer signed an informed consent. The study was approved by the Ethical Committee of Ghent University Hospital.

*Table 1. Subject characteristics**

Characteristic	Control group (n = 53)	Instability group (n = 10)	Group 3 (n = 16)	Group 4 (n = 8)
Age (years)	18.3 ? 1.2	18.3 ? 1.1	18.1 ? 0.2	19.4 ? 2.4
Height (cm)	174.9 ? 9.0	173.5 ? 8.4	173.9 ? 7.5	170.2 ? 8.3
Mass (kg)	66.1 ? 7.7	65.7 ? 11.2	67.0 ? 6.6	64.9 ? 10.1

* Mean \pm SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.

INSTRUMENTATION AND PROTOCOL

Proprioception

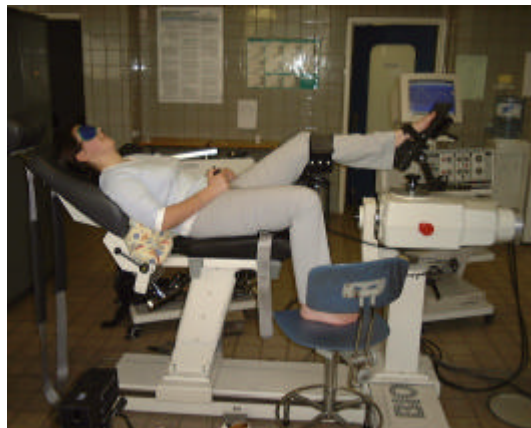
Active and passive joint position sense was assessed using the Biodex 2 isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY)(Figure 1). Each subject was positioned supine on the associated chair, with the calf of the tested leg resting on a 40-cm-high platform. The bare foot of the subject was aligned with the axis of the dynamometer and attached to the footplate by a very small wrap to reduce cutaneous receptor input. The talocrural joint was in 15° of plantar flexion. The lower leg was secured to the platform by hook-and-loop straps. Two positions were tested: 15° of inversion and maximal active inversion minus 5°. Subjects were blindfolded throughout the examination.

For passive testing, the subject's foot was first passively moved by the investigator to maximal eversion. The investigator then moved the foot to 1 of the 2 test positions, randomly determined. The test position was maintained for 10 seconds, with each subject instructed to concentrate on the position of the foot. The foot was then passively brought to maximal eversion and moved passively back toward inversion with a speed of 5°/s. The

subject was instructed to push on a stop button when he or she thought the test position had been reached. The subject was tested twice at each of the 2 test positions. The active test was performed in the same manner, except after having the foot passively placed in the test position and moved to the maximal eversion, the subject was asked to move the foot actively back to the test position. The subject was again asked to push on the stop button when he or she thought the test position was reached. The testing order, test positions, and side of body tested were randomly chosen. The amount of error in degrees was noted for further analysis.

We examined 3 types of errors in the subjects' ability to match the reference angles: the absolute, exact, and variable error. Average scores of the 2 trials were used for analysis. The absolute error is the difference in absolute value in degrees between the position chosen by the subject and the test-position angle. The exact error, calculated as the difference between the chosen position and the test-position angle, provides an indication of whether the subjects tended to, on average, systematically overshoot (positive exact error) or undershoot (negative exact error) the test-position angle. The variable error, which was calculated as the standard deviation of the exact error, provides an indication of the random error in matching the test-position angle.

Figure 1. Positioning of the subject for testing active and passive joint-position sense on the Biodex 2 isokinetic dynamometer



Muscle strength

We used a Biodex System 3 Dynamometer and Biodex Advantage Software Package (Biodex Medical Systems Inc, Shirley, NY) to determine isokinetic peak torque and peak torque/body-weight values for reciprocal concentric and eccentric eversion-inversion movements of the ankle (Figure 2). Subjects were tested in a semirecumbent position with

30° of seatback tilt. The ankle was in 10° of plantar flexion. The knee of the tested ankle was in extension to minimize substitution from the hamstrings and other tibial rotators. Dynamometer and chair adjustments were made to align the midline of the foot with the midline of the patella. Two straps were wrapped around the extremity proximal to the patella and the pelvis to minimize movements of the hip and knee during testing. Subjects wore their own athletic shoes during testing; each shoe was tightly secured with 2 straps to the dynamometer footplate to minimize movement between the shoe sole and the footplate surface. The tested range of motion was maximal active inversion and eversion minus 5° for both directions. The first test consisted of 3 maximal repetitions of concentric-eccentric eversion at 30°/s to assess the strength of the evertor muscles. The second test for the same ankle consisted of 5 repetitions of concentric-eccentric eversion at 120°/s. The same 2 tests (concentric-eccentric at 30°/s and 120°/s) were performed for inversion to assess the strength of the inversion muscles. The same 4 tests were then performed with the contralateral limb. The first tested ankle was randomly chosen. Before data collection, each subject was given an opportunity to become familiar with the testing procedure and to perform 3 warm-up repetitions. Consistent verbal encouragement for maximal effort was given to each subject throughout the testing procedure. None of the subjects felt any discomfort while testing.

Peak torque and peak torque/body-weight values were obtained for each ankle motion (concentric and eccentric) of each limb at the 2 speeds. Eversion-to-inversion strength ratios and eccentric-to-concentric strength ratios were calculated.

Figure 2. Positioning of the subject for testing isokinetic ankle inversion/eversion on the Biodex 3 isokinetic dynamometer



Statistical analysis

Statistical Package for the Social Sciences (SPSS) for Windows (version 10.0, SPSS Inc, Chicago, IL) was used for statistical analysis. The exact, absolute, and variable data from the proprioception test were examined with a nonparametric Kruskal-Wallis test to determine significant differences among the 4 groups. Peak torque, peak torque/body-weight values, and eversion-to-inversion and eccentric-to-concentric strength ratios were also analyzed for between-group differences. Post hoc comparisons of means were accomplished with Mann-Whitney *U* tests and corrected with the Bonferroni correction. Additionally, a Pearson correlation analysis was performed between peak torque and body weight. A significance level of $P < .05$ was used throughout the data analysis.

RESULTS

Proprioception

For the absolute error, we found no significant differences among the 4 groups for either active or passive joint-position sense (Table 2). For the exact error, a significant difference was noted for the active joint-position sense in the test position of maximal inversion minus 5° ($P = .012$) (Table 3). The instability group showed a significantly lower value for active joint-position sense at maximal inversion minus 5° compared with the control group ($P = .042$), group 3 ($P = .012$), and group 4 ($P = .036$). No significant differences were observed for the variable error among the 4 groups.

Table 2. Absolute error on the proprioception test *

Variables	Control group	Instability group	Group 3	Group 4	<i>P</i> value
Active joint-position sense					
Maximal active inversion minus 5°	3.06 ? 2.05	3.89 ? 2.07	2.40 ? 1.61	2.50 ? 1.95	.161
15° of inversion	3.86 ? 3.06	4.25 ? 2.96	3.90 ? 2.59	4.50 ? 3.34	.826
Passive joint-position sense					
Maximal active inversion minus 5°	6.49 ? 5.52	6.64 ? 5.97	7.05 ? 4.31	5.19 ? 3.20	.784
15° of inversion	7.90 ? 4.88	7.68 ? 3.95	9.02 ? 3.73	8.50 ? 4.80	.572

* Values are mean degrees \pm SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.

Table 3. Exact error on the proprioception test*

Variables	Control group	Instability group	Group 3	Group 4	P value
Active joint-position sense					
Maximal active inversion minus 5°	-0.68 ? 3.21	-2.96 ? 2.96	0.10 ? 2.47	0.62 ? 2.79	.012†
15° of inversion	-1.58 ? 3.64	-3.25 ? 3.18	-1.65 ? 4.21	-2.37 ? 4.90	.218
Passive joint-position sense					
Maximal active inversion minus 5°	-5.83 ? 5.93	-5.93 ? 6.68	-6.50 ? 4.67	-4.56 ? 3.63	.889
15° of inversion	-7.27 ? 5.58	-7.18 ? 4.64	-7.97 ? 5.18	-7.87 ? 5.39	.857

* Values are mean degrees \pm SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.

†Significant difference among the 4 groups ($P < .05$)

Muscle strength

We found significant differences in the strength of the eversion muscles compared with body weight at both speeds (30°/s and 120°/s) for concentric and eccentric test conditions (Table 4). The instability group had a significantly lower value compared with the control group for eversion strength/body weight at 30°/s for both concentric ($P = .048$) and eccentric ($P = .024$) test conditions and at 120°/s for the eccentric condition ($P = .024$). The instability group also had a significantly lower value compared with group 3 for eversion strength/body weight at 120°/s ($P = .024$) and with group 4 for eversion strength/body weight at 30°/s ($P = .018$), both for the eccentric condition. There were no significant differences for strength/body weight between the control group and the other 2 groups that sustained ankle sprains in the past without instability as complaint. No significant differences were observed among the 4 groups for peak torque, inversion-to-eversion strength ratio, or eccentric-to-concentric strength ratio ($P > .05$).

We noted a significant association between inversion and eversion peak torque and bodyweight ($P < .001$, $.47 < r > .60$) for the concentric and eccentric conditions and for both speeds.

Table 4. Muscle strength*

Variables	Control group	Instability group	Group 3	Group 4	P value
Eversion (Nm)					
30°/s concentric	27.09 ? .99	21.44 ? 2.13	26.48 ? 2.12	30.80 ? 4.97	0.207
30°/s eccentric	29.02 ? .86	25.23 ? 2.09	28.09 ? 1.83	31.07 ? 3.82	0.475
120°/s concentric	24.88 ? .78	21.87 ? 1.93	25.53 ? 1.40	27.70 ? 3.63	0.405
120°/s eccentric	30.60 ? .87	26.57 ? 2.30	31.48 ? 1.39	30.27 ? 3.65	0.445
Inversion (Nm)					
30°/s concentric	28.49 ? .92	29.80 ? 2.89	29.46 ? 2.16	29.16 ? 3.24	0.916
30°/s eccentric	28.97 ? .75	29.66 ? 1.87	29.79 ? 1.48	28.91 ? 2.84	0.939
120°/s concentric	25.30 ? .66	24.57 ? 1.69	27.21 ? 1.63	25.54 ? 3.22	0.709
120°/s eccentric	30.43 ? .73	30.22 ? 1.96	30.93 ? 1.51	29.54 ? 2.36	0.964
Eversion (Nm/kg)					
30°/s concentric/body weight	0.41 ? .01	0.31 ? .02	0.38 ? .02	0.48 ? .05	0.015* ^a
30°/s eccentric/body weight	0.44 ? .01	0.35 ? .02	0.40 ? .02	0.50 ? .04	0.006* ^b
120°/s concentric/body weight	0.38 ? .01	0.30 ? .02	0.36 ? .01	0.45 ? .05	0.040* ^c
120°/s eccentric/body weight	0.46 ? .01	0.36 ? .02	0.44 ? .01	0.47 ? .04	0.021* ^d
Inversion (Nm/kg)					
30°/s concentric/body weight	0.43 ? .01	0.42 ? .31	0.43 ? .03	0.46 ? .03	0.880
30°/s eccentric/body weight	0.44 ? .01	0.42 ? .02	0.43 ? .02	0.46 ? .04	0.738
120°/s concentric/body weight	0.38 ? .01	0.35 ? .02	0.39 ? .02	0.40 ? .03	0.433
120°/s eccentric/body weight	0.46 ? .01	0.40 ? .04	0.45 ? .02	0.46 ? .03	0.368
Eversion/Inversion					
30°/s concentric	1.00 ? .36	0.83 ? .22	0.97 ? .34	1.10 ? 0.2	0.318
30°/s eccentric	1.01 ? .29	0.90 ? .24	0.98 ? .25	1.07 ? 0.3	0.654
120°/s concentric	1.02 ? .26	0.87 ? .21	0.91 ? .34	1.10 ? 0.2	0.230
120°/s eccentric	1.01 ? .24	0.86 ? .23	1.01 ? .26	0.99 ? 0.1	0.331
Eversion					
30°/s eccentric/concentric	1.10 ? .02	1.11 ? .03	1.07 ? .03	1.04 ? .06	0.567
120°/s eccentric/concentric	1.24 ? 0.02	1.23 ? .02	1.22 ? .03	1.17 ? .05	0.635
Inversion					
30°/s eccentric/concentric	1.05 ? .02	1.07 ? .08	1.04 ? .04	1.01 ? .04	0.849
120°/s eccentric/concentric	1.22 ? .02	1.19 ? .03	1.16 ? .03	1.20 ? .08	0.347

* Mean \pm SD. Subjects in group 3 had sustained 1 to 3 inversion sprains in the previous 2 years but had no instability or other symptoms. Subjects in group 4 had sustained 1 to 3 inversion sprains 3 to 5 years before testing but had no instability or other symptoms.

* Significant difference among the 4 groups ($P < .05$).

^a Significant difference between the instability group and control group ($P = .048$).

^b Significant difference between the instability group and control group ($P = .024$) and between the instability group and the group with sprain 3-5 years earlier ($P = .018$).

^c No significant differences among the groups after the Bonferroni correction was applied.

^d Significant difference between the instability group and the control group ($P = .024$) and between the instability group and the group with sprain 1-2 years earlier ($P = .024$)

DISCUSSION

Proprioception

It is widely believed that the tendency for ankle sprains to recur is due to a proprioceptive deficit caused by deafferentation during the original trauma.¹ Many methods have been devised to assess ankle proprioception, such as quantification of postural sway in standing

using instant single-leg stance,¹⁸ stance on a wobble board,¹⁹ and standing with eyes open or closed.²⁰ These techniques do not isolate variations in performance to the ankle region and may involve other factors such as visual and vestibular cues, neuromuscular control, and the influence of other joints²¹; however, these techniques have the advantage of testing in the weight-bearing position.²¹ Although visual and vestibular inputs contribute to proprioception, the peripheral mechanoreceptors are most important from a clinical orthopaedic perspective. These peripheral mechanoreceptors include cutaneous, muscle, and joint types. The neural input provided by these mechanoreceptors and the visual and vestibular receptors are all integrated by the central nervous system to generate a motor response. These responses generally may be categorized within 3 levels of motor control: spinal reflexes, brain stem activity, and cognitive programming. Quantifying the reproduction of joint position (either active or passive) and the detection of changes in joint position is processed at the highest level of organization: the somatosensory cortex. These methods can objectively isolate the measurement of joint position at the ankle, although in a non-weight-bearing position. Our study involved a protocol simulating positions associated with the most common mechanism of injury for the ankle joint: inversion and plantar flexion.

Our results show 2 ways to interpret proprioceptive data: the absolute and exact error. Most previous investigators of joint position sense have examined only absolute errors.^{9-11,21} These studies lack a distinct measure of whether subjects were systematically biased to overestimate or underestimate the reference angle. In our study, the exact error was usually negative; thus, our subjects were mostly biased to undershoot the test-position angle. These data do not support the findings of Feuerbach et al.²², who found that the exact error was not significantly different from zero for subjects without injuries. Measuring proprioception in different planes could cause these conflicting results. In this study, proprioception was measured in 1 plane (inversion-eversion). Subjects studied by Feuerbach et al.²² were required to match test positions in 3 planes.

We demonstrated no significant differences among the 4 groups for the absolute error; however, we found a difference between the instability group and the other groups for the exact error. Subjects with unstable ankles did not differ from the others in matching the reference position; none were able to perfectly match the reference angle, but the subjects with unstable ankles systematically underestimated the reference angle whereas the other subjects sometimes underestimated and sometimes overestimated the reference angle.

Gross,¹⁰ who examined active and passive joint-position sense in the inversion-eversion plane, did not find significant differences between controls and subjects with recurrent ankle sprains. Holme et al.¹¹ also noted no difference in active joint-position sense in the inversion-eversion plane between the injured and uninjured ankles of subjects with a unilateral ankle sprain. These studies only investigated the absolute error and therefore lack distinction in direction. Our observed differences between the unstable and stable ankles in this study in the exact error agree with previous investigations.^{9,21,23} Some studies have reported less accurate joint-position sense in chronically unstable ankles. Glencross and Thornton⁹ reported postinjury deficits in judgment of active joint-position sense in the plantar flexion-dorsiflexion plane. Boyle and Negus²¹ found significantly less accurate judgment of active and passive joint-position sense in subjects with recurrent ankle sprains compared with uninjured subjects. Hartsell²⁴ also showed those with chronically unstable ankles to have poorer active joint-position sense awareness than did those with healthy ankles at a test position of 15° inversion.

Our results for the exact error indicated that subjects with instability had a significantly less accurate active joint-position sense at maximal inversion minus 5°. Correct positioning of the foot is very important in gait and sports. Hitting the ground in an overly inverted position could result in spraining the ankle. Our findings suggest that subjects with CAI may have inappropriate foot positioning. Because of the altered afferent input, these subjects may be more susceptible to ankle reinjury.

Interestingly, we found no significant differences between the control group and the 2 groups of subjects who had sustained ankle sprains in the past. We demonstrated significant differences between the ankles that had previously sustained an inversion sprain not associated with instability and the chronically unstable ankles. Therefore, past ankle sprains without resultant instability did not affect an individual's ability to judge ankle position.

Because subjects with past sprains without instability had normal proprioception, the proprioceptive deficit may be the reason for ankle sprains recur in patients with CAI. One of the main goals in the treatment of lateral ankle injuries should be the prevention of CAI. Joint position sense is affected in subjects with CAI, and taping or bracing may counterbalance this deficit. Previous studies have already shown that taping and bracing reduce the error in joint position sense.^{22,24} Feuerbach et al.²² suggested that application of an orthosis may increase the afferent feedback from cutaneous receptors, which may lead

to improved ankle joint-position sense. This increased stimulation could result in a more appropriate positioning of the unstable ankle and may protect it from reinjury.

Muscle strength

Many investigators have found a relationship between peroneal muscle weakness and chronically unstable ankles.^{12-14,23} Others have found significant inverter weakness in the chronically unstable ankles.^{19,23} Ryan¹⁹ suggested that the inverter weakness could be the result of interruption of the muscles' nerve supply or the result of selective inhibition of the invertors' ability to start moving in the direction of initial injury. However, we found no relationship between inverter muscle strength and ankle sprains, although we did find a significant difference for evertor muscle strength (peak torque/body weight) between subjects with CAI and the control group. Subjects with CAI seemed to have less concentric and eccentric evertor muscle strength than normal subjects.

Previous investigators have tested evertor and inverter muscle strength at different speeds. We chose to use 30°/s and 120°/s to measure muscle peak torque because slower speeds, identified in the literature as those between 30°/s and 120°/s, define strength, while the faster speeds, identified in the literature as those between 120°/s and 300°/s, define muscle power.²⁵ Otherwise, high-velocity eccentric contractions are not without risk and are very hard to perform.

Most researchers report only mean peak-torque values rather than values normalized by body weight. We find the peak torque for both muscle groups at both speeds to be significantly related to body weight. Normalizing by body weight is, thus, an important consideration for a better comparison among subjects of varied body types. Additionally, as inversion sprains most often occur in closed kinetic chain, body weight also has an influence on the inversion moment generated at the ankle. Therefore, we consider peak torque/body weight a more relevant value compared with peak torque. In addition, the functional assessment of muscular stabilization must consider the fact that the evertor muscles contract eccentrically to resist an inversion trust.¹⁶ Nevertheless, isokinetic assessment of ankle muscles has traditionally been tested by concentric contractions only. Hartsell and Spaulding²³ were the first to retrospectively test the strength of the inverter and evertor muscles eccentrically in subjects with healthy and chronically unstable ankles. Chronically unstable ankles were significantly weaker concentrically and eccentrically for both inversion and eversion. Although we did not find significant differences among the

groups for inversion muscle strength, we did find the unstable ankles weaker concentrically and eccentrically for eversion strength/body weight at both speeds.

Hartsell and Spaulding²³ calculated eccentric/concentric ratios at several velocities (60, 120, 180 and 240°/s). Their hypothesis was that the eccentric/concentric ratios would be significantly different for subjects with CAI because abnormalities in the ratio may imply pathology or predispose to injury.²⁶⁻²⁸ Bennett and Stauber²⁸ tested patients with knee problems who showed a deficiency in eccentric activity. They found a particularly low eccentric/concentric ratio and proposed that this was a potential cause of patellofemoral problems. The problem was proposed to be related to an error in the neuromotor control of the quadriceps muscle, although another feasible explanation may be selective inhibition of eccentric performance of the quadriceps as the result of pain. Although Hartsell and Spaulding²³ tested subjects with healthy and chronically unstable ankles over a velocity continuum, they were not able to identify an eccentric/concentric ratio pattern suggestive of instability. Our results affirm these findings of no significant differences for the eccentric/concentric ratio between subjects with healthy ankles and those with unstable ankles or ankles with past inversion sprains. Perhaps the invertor and evertor muscles produce too little torque in relation to the quadriceps muscles to display differences in eccentric/concentric ratios.

In a prospective study of ankle-injury risk factors, Baumhauer et al.¹⁵ found that individuals with a muscle-strength imbalance, as measured by an elevated eversion-to-inversion ratio, exhibited a higher incidence of inversion ankle sprains. We examined this factor retrospectively in uninjured subjects and subjects with instability or past sprains and noted no significant differences among the groups.

As in the proprioception test, none of the variables tested showed significant differences between the control group and the 2 groups of subjects who had previously sustained ankle sprains without instability. Interestingly, some eversion-strength factors showed significantly higher values for the groups with past sprains compared with the instability group. This could mean that a deficit in muscle strength is one cause of instability; however, it is difficult to say whether these findings are the cause or the effect of the instability. Probably the 2 tested components, proprioception and muscle strength, both play a role in ankle instability. We suggest that neuromuscular disorders such as proprioceptive deficits and muscle weakness may cause persistent instability of the ankle. We also think that subjects who sustain an inversion sprain without associated CAI are at

less risk to resprain their ankles than subjects with CAI because they have greater muscle strength and more accurate joint position sense.

CONCLUSION

Chronic instability was significantly related to active joint-position sense in the ankle at angles near maximal inversion. Ankle instability and evertor muscle weakness coexists; however, we found no evidence for a lack of muscle strength or proprioception deficit in subjects who sustained sprains in the past without instability as a complaint.

We suggest that a possible cause of recurrent sprains in the instability group is the combined action of diminished proprioception and evertor muscle weakness. If the ankle is inverted at the moment the foot touches the ground, due to the diminished proprioception, the result could be a varus thrust from an inversion lever through the subtalar axis. If the evertor muscles are not strong enough to counteract this motion, the tensile strength of the lateral ligaments may be exceeded, resulting in injury.

Our results affirm the importance of proprioception training and strength training of the peroneal muscles in the rehabilitation of ankle injuries. These exercises may effectively stabilize an unstable ankle and break the vicious cycle of recurrent sprains and subsequent loss of proprioception and muscle atrophy.

Acknowledgements

We thank Guy Vanderstraeten, MD, PhD, for assistance in revising the manuscript.

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CHAPTER 3

INTRINSIC RISK FACTORS FOR INVERSION ANKLE SPRAINS IN MALE SUBJECTS – A PROSPECTIVE STUDY

**Tine M. Willems¹ PT, Erik Witvrouw¹ PT PhD, Kim Delbaere¹ PT,
Nele Mahieu¹ PT, Ilse De Bourdeaudhuij² PSY PhD, Dirk De Clercq² PE PhD**

¹ Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, Ghent University, Belgium

² Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, Belgium

Am J Sports Med, in press, August 2004

ABSTRACT

Background: Many variables have been retrospectively associated with ankle sprains. However, very little is known about factors predisposing people to these injuries.

Hypothesis: Measurable intrinsic factors might predispose males to ankle sprains.

Study design: Prospective cohort study

Methods: A total of 241 male physical education students were evaluated for possible intrinsic risk factors for inversion sprains at the beginning of their academic study. The evaluated intrinsic risk factors included anthropometrical characteristics, functional motor performances, ankle joint position sense, isokinetic ankle muscle strength, lower leg alignment characteristics, postural control, and muscle reaction time during a sudden inversion perturbation. Subjects were followed prospectively for 1 to 3 years.

Results: A total of 44 (18%) of the 241 male subjects sustained an inversion sprain; 4 sprained both ankles. Cox regression analysis revealed that male subjects with slower running speed, less cardiorespiratory endurance, less balance, decreased dorsiflexion muscle strength, decreased dorsiflexion range of motion, less coordination, and faster reaction of the tibialis anterior and gastrocnemius muscles are at greater risk of ankle sprains.

Conclusion: Based on our findings, it is suggested that running speed, cardiorespiratory endurance, balance, dorsiflexion strength, coordination, muscle reaction, and dorsiflexion range of motion at the ankle are associated with the risk of ankle inversion sprains in male subjects.

Key words: cause, anthropometrical characteristics, functional motor performance, proprioception, muscle strength, alignment, postural control, muscle reaction time

INTRODUCTION

Lateral ankle sprain is an extremely common athletic injury. In view of the high frequency of injury, not only in professional sports but also during leisure-time activities, it is clear that analyses of risk factors for sports injuries are urgently required as a prerequisite to the development of prevention programs.²² Murphy et al.⁴³ recently reviewed the literature on the risk factors for lower extremity injuries and demonstrated that our understanding of injury causation is limited. They concluded that more prospective studies are needed, emphasizing the need for proper design and sufficient sample sizes.

Sports injuries are multi risk phenomena with various risk factors interacting at a given time.⁴⁰ In general, a distinction has been made between so-called intrinsic (person-related) and extrinsic (environment-related) risk factors.^{36,51,55} The intrinsic risk factors are related to the individual characteristics of a person. Extrinsic risk factors relate to environmental variables such as the level of play, exercise load, amount and standard of training, position played, equipment, playing field conditions, rules, foul play, and so forth.

Although ankle sprains are frequently encountered in the sports injury clinic, the causes of this injury remain enigmatic. Beynnon et al.⁴ revealed that investigations on extrinsic risk factors for ankle sprains arrived at some agreements, but at this point there is little consensus with regard to the intrinsic risk factors. One of the most important reasons is probably the lack of well-designed prospective investigations designed to determine risk factors for inversion sprains. Therefore, the relationship between intrinsic parameters and ankle sprains is still obscure. With the current emphasis on injury prevention, studies designed to examine potential ankle injury intrinsic risk factors are imperative. Based on a review of the literature, several possible intrinsic risk factors were defined. Most of the evaluated variables have retrospectively been associated with ankle sprains. These variables range from diminished muscle strength,^{20,42,48,57} diminished postural control,^{17,18,30,33} diminished proprioception,^{19,29,32} malalignment,^{34,49,60} to delayed muscle reaction time.^{6,23,44} However, it is unclear if any of these deficits were present before injury because of the retrospective design of these studies. Distinguishing among these possible intrinsic causes can be challenging.

The purpose of this investigation was to perform a comprehensive, prospective investigation of risk factors for inversion sprains. A prospective cohort study was conducted in a young, physically active, male population. The factors examined included

anthropometrical characteristics, functional motor performances, ankle joint position sense, ankle muscle strength, lower leg alignment, postural control, and muscle reaction time.

MATERIALS AND METHODS

Subjects

The subjects were 241 male physical education students (age range: 17-28 years; mean age: 18.3 ± 1.1 years), who were freshman in 2000-2001, 2001-2002 and 2002-2003 in Physical Education at the Ghent University, Belgium. All students were tested at the beginning of their education for several possible intrinsic risk factors. Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria were history of a surgical procedure involving the foot or ankle, previous grade II or III inversion ankle sprains, or history of an injury to the lower leg, ankle or foot within 6 months of the start of the study. None of the subjects used prophylactic ankle bracing or taping before or during the study. Information on foot dominance was obtained by asking the subjects which foot they normally use to kick a ball.

At the university level, the students all followed the same sports program under the same environmental conditions for 26 weeks per academic year. All students used the same sports facilities, and the safety equipment was uniform. The workout program in the first year consisted of 45 minutes of soccer, handball, basketball and volleyball; 1 hour of track and field, gymnastics, karate and swimming; and 2 hours of dance every week. In the second year, the weekly workout program consisted of half an hour of climbing; 1 hour of track and field, soccer, handball, basketball, volleyball, karate and swimming; 1,5 hours of gymnastics; and 2 hours of dance. In the third year, the program consisted of half an hour of track and field, volleyball, soccer, gymnastics, orienteering and swimming; and 1 hour of handball, basketball, badminton, dance and judo every week. Extramural activities, being the amount of physical activities students participate in beyond their sports lessons at school, were also registered.

All volunteers signed an informed consent form. The study was approved by the Ethical Committee of the Ghent University Hospital.

The students were followed weekly by the same sports physician for occurrence of injury throughout 3, 2, and 1 academic years for freshman in 2000-2001, 2001-2002, and 2002-2003, respectively. The subjects were asked to report all injuries resulting from sports

activities to this physician. All sports injuries sustained during practice, lessons, and games were registered. The injury definition was based on that of the Council of Europe.¹¹ The definition requires that an injury have at least 1 of the following consequences: 1) a reduction in the amount or level of sports activity, 2) a need for (medical) advice or treatment or 3) adverse social or economic effects.¹¹ Injury data were recorded on a standardized injury form that captured basic information about type of injury, the circumstances under which the injury occurred, and the treatment of the injury.

Instrumentation and protocol

Before the start of their physical education, all students were tested for anthropometrical characteristics, functional motor performances, ankle joint position sense, muscle strength, lower leg alignment, postural control, and muscle reaction time.

Anthropometrical characteristics

The following anthropometric measurements were evaluated: height (in centimeters), mass (in kilograms), calf girth, humerus and femur width (epicondyle width), and biceps, triceps, subscapular, suprailiac, and medial calf skin folds. Measurements were carried out by the same trained anthropometrist after the procedures as described by Claessens et al.⁹ The body mass indices [BMI = mass (kg)/height (m)²], and ponderal indices [PI = height (m)/mass (kg)^{1/3}] were calculated. The 3 somatotype components (endomorph, mesomorph and ectomorph) were calculated using the anthropometric method according to Carter and Heath.⁷ Body composition characteristics (fat mass, percent fat and fat-free mass, density) were estimated based on the formula of Durnin and Womersley¹² using the Siri equation.⁵⁰

Functional motor performances

Functional motor performances, such as general balance, explosive jump ability, and running speed, were evaluated using the European Test of Physical Fitness.¹⁰ These performances were evaluated by means of a flamingo balance, a standing broad jump and the shuttle run test, all of which have good validity and reliability.^{10,35,45} Cardiorespiratory endurance was measured by the endurance shuttle run described by Leger et al.³¹ All tests were performed with standard equipment and by trained observers, physical therapists, and physical educators who were educated to administer the tests.

Joint position sense

Active and passive joint position sense was assessed using the Biodex System 2 Isokinetic Dynamometer (Biodex Medical Systems Inc, Shirley, NY). Positioning of the subject has been described previously.⁵⁹ For passive testing, the subject's foot was first passively moved by the investigator to maximal eversion (for inversion test positions) or inversion (for eversion test position). The investigator then moved the foot to 1 of the 3 test positions: 15° of inversion, maximal active inversion minus 5°, or 10° of eversion, randomly determined. The test position was maintained for 10 seconds. During these 10 seconds, subjects were instructed to concentrate on the position of the foot. The foot was then passively brought to maximal eversion (for the inversion test positions) or to maximal inversion (for the eversion position) and moved passively back toward the other direction with a speed of 5°/s. The subject was instructed to push a stop button when he thought the test position had been reached. The subject was tested twice at each of the 3 test positions. The active test was performed in the same manner, except after having the foot passively placed in the test position and moved to maximal eversion or inversion, the subject was asked to move the foot actively back to the test position. The subject was again asked to push the stop button when he thought the test position was reached. The testing order, test positions, and side of body tested were randomly chosen. The amount of error in degrees was noted for further analysis.

We examined 2 types of errors in the subjects' ability to match the reference angles: the absolute error and the exact error.⁵⁹ Average scores of the 2 trials were used for analysis. Konradsen et al.²⁸ validated a comparable method of measuring ankle position sense and found it to be accurate, repeatable, and precise.

Muscle strength

A Biodex System 3 Isokinetic Dynamometer and Biodex Advantage Software Package (Biodex Medical Systems Inc) were used to determine isokinetic peak torque and peak torque compared to body mass values for reciprocal concentric and eccentric eversion-inversion movements of the ankle and for concentric plantar flexion-dorsiflexion. Positioning and stabilization has been described elsewhere.⁵⁹ The protocol for testing plantar flexion-dorsiflexion and inversion-eversion muscle strength was recommended by Dvir¹³ and was found to be reliable.²⁴

The tested range of motion for the inversion-eversion test was maximal active inversion and eversion minus 5° for both directions and for plantar-dorsiflexion it was maximal active plantar flexion and dorsiflexion. The first test consisted of 3 maximal repetitions of concentric-eccentric eversion at 30°/s to assess the strength of the eversion muscles. The second test for the same ankle consisted of 5 repetitions of concentric-eccentric eversion at 120°/s. The same 2 tests (concentric-eccentric at 30°/s and 120°/s) were performed for inversion to assess the strength of the inversion muscles. The same 4 tests were then performed with the contralateral limb. Next, plantar flexors and dorsiflexors were tested concentrically at 30°/s (3 repetitions) and at 120°/s (5 repetitions). The order of testing the ankles was randomized. Before data collection, each subject was provided an opportunity to become familiar with the testing procedure and to perform 3 warm-up repetitions. Consistent verbal encouragement for maximal effort was given to each subject throughout the testing procedure. None of the subjects felt any discomfort while testing.

Peak torque and peak torque compared to body mass values were obtained for each ankle motion of each limb at the 2 speeds. Eversion-to-inversion and dorsiflexion-to-plantar flexion strength ratios were calculated.

Lower leg alignment

Lower leg alignment characteristics were determined using goniometric measurements by the same experienced physical therapist. At the talocrural joint, plantar flexion and dorsiflexion range of motion with the knee straight and flexed were measured using the method described by Ekstrand et al.¹⁴ Inversion and eversion at the subtalar joint and position of the calcaneus, unloaded with the subtalar joint in neutral position, were measured. In addition, position of the calcaneus was measured in stance with and without the subtalar joint in neutral position.¹⁶ Flexion and extension range of motion at the first metatarsophalangeal joint was also determined. Hip external and internal rotation were measured using the method described by Khan et al.²⁶ Talocrural, subtalar and hip goniometric measurements appear to be moderately to highly reliable.^{14,15,26} We checked test-retest reliability of the goniometric measurements of the first metatarsophalangeal joint on 12 feet. The intraclass correlation coefficients were between .82 and .98.

Postural control

Postural control was assessed through 5 tests using the Neurocom Balance Master (NeuroCom Int, Inc, Clackamas, Oregon). The first test (weightbearing) evaluated the percentage of weight borne by each leg. The second test assessed sway velocity of the center of gravity in bilateral positions with eyes open and closed and on firm and foam surfaces. Three trials of each test condition were performed, each of which required 10 seconds. The third test evaluated sway velocity in unilateral stance with eyes open and closed. Again 3 trials were performed for 10 seconds on both sides. The next test (limits of stability) quantified several movement characteristics associated with the subject's ability to voluntarily sway his center of gravity to various locations in space (forward, right, back, and left), and briefly maintain stability at those positions. Subjects were asked to move as quickly and as straight as possible to a specific target. The measured parameters were reaction time, sway velocity, directional control, endpoint excursion (distance at which the initial movement attempt stops or reverses), and maximal excursion (furthest distance the subject reaches on any attempt at the target). The last test (forward lunge) quantified several movement characteristics. The subject was instructed to lunge forward with 1 leg and then to return to a standing position. The parameters measured were distance, time, impact index (impact force), and force impuls. The test was repeated 3 times. A mean value of the 3 trials was calculated for each condition and was used for analysis.

Reliability of the postural control tests on the Neurocom Balance Master was good to excellent.⁵⁴

Muscle reaction time

To measure the muscle reaction time to a sudden inversion perturbation, a specially designed platform that allowed each foot to drop into plantar flexion/inversion of 50° from standing in 40° plantar flexion and 15° adduction was used.⁵³ The movement of the platform was recorded by an electrogoniometer and an accelerometer installed on the tilting axis. Before electrode application, the skin was shaved, grazed with sandpaper, and cleaned with alcohol. Surface EMG was used to capture muscle activity of the following muscles: peroneus longus, peroneus brevis, tibialis anterior and the gastrocnemius. All electrodes were placed according to the protocol described by Basmajian and De Luca.² The correct placements were verified by particular movements of the foot, causing isolated contractions of the muscles to be examined, and specific EMG patterns were observed

online on the monitor. Telemetric measurements were performed by means of the Myosystem (Noraxon USA Inc, Scottsdale, Ariz). All EMG signals were sampled and analogue to digital converted (12-bit resolution) at 1000 Hz.

Subject was asked to stand in their sport shoes fixed on the platform with their body mass equally distributed on each foot. Subjects were blindfolded and wore a headphone to eliminate visual and auditory cues to the platform release. In random order, 5 measurements were performed on each side. When EMG signals showed baseline activity, the tilting platform was released. All data were saved on computer for further analysis. The protocol used has been demonstrated to be satisfactory to highly reproducible.⁵³

A software package (Myoresearch 2.10, Noraxon USA Inc) was used for determination of the muscle reaction time. The beginning of the tilting movement by the accelerometer was marked visually. The muscle reaction time was determined by the period of time between the start of platform tilting and the onset of muscle activity. The threshold for muscle activity was set at 2 standard deviations above the baseline activity and this activity had to last at least 3 milliseconds. The baseline activity in the muscles was measured during 1 second before the start of the tilting. Average scores of the 5 trials were used for statistical analysis.

Analysis

SPSS for Windows (version 10.0, SPSS Science Inc, Chicago, Ill) was used for statistical analysis. The students were divided into 2 groups: an uninjured group as control group (group 1) and a group with subjects who sustained an inversion sprain (group 2). Group 1 consisted of the control subjects who did not have any injury to either leg in the period they were followed in this study. A stratified randomization technique was used: 1 of the 2 uninjured legs was randomly selected, taking into account the percentage of dominant legs in the inversion sprain group. Group 2 consisted of the subjects who sustained an inversion sprain. Only the data from the injured legs were used for analysis. A Cox proportional hazard regression was used to test the effect of each variable on the hazard of injury, taking into account differences in the length of time that the athletes were at risk. This approach has been chosen for statistical analysis because this method can adjust for the fact that the amount of sport participation can vary between the students. The time from the start of the follow-up period until the ankle sprain or the end of the follow-up period for students who were not injured was the main variable. Time was measured as the number of hours of

sport exposure for each student. This was accomplished by computing time at risk as the total number of hours of sports lessons, practices for sports lessons, practices for recreational or competition sports, and games in which each subject participated until injury or, if uninjured, the end of the period students were followed. This analysis also took censorship into account, such as abbreviated length of follow up for other reasons than injury (e.g., not passing). The method assumes that risk factors affect injury in a proportional manner across time.¹

RESULTS

During the follow-up period, 44 (18%) of the 241 subjects suffered 1 or more inversion sprains; 4 of the 44 subjects sprained both ankles. Only the initial sprain was used for analysis when repeated sprains occurred. A total of 108 (45%) of the 241 subjects did not sustain any injuries of the lower leg, ankle or foot and served as the control group.

In 59% of the ankle sprains, the dominant foot was affected. Twenty-one (44% of all ankle sprains) ankle sprains were sustained during lessons at the university, 3 (6%) during practice for lessons, 12 (25%) during extramural competition, 9 (19%) during extramural training for competition, and 3 (6%) during extramural recreational sports. Twenty (42% of all ankle sprains) sprains occurred during soccer, 5 (10%) during basketball, 4 (8%) during volleyball, 8 (17%) during track and field, and 4 (8%) during gymnastics. The rest of the ankle sprains (15%) happened during other sports, in which the incidence of ankle sprains was low.

Figure 1 displays the survival curve of the students with an ankle sprain. Anthropometric data on the subjects are listed in Table 1. No significant differences were found between the uninjured group and the ankle sprain group for any of the measured anthropometric data ($P > .05$). Table 2 represents the evaluated functional motor performances. Cox regression revealed that subjects who scored worse on the flamingo balance test were at greater risk of ankle sprains ($P = .001$). In addition, subjects with a slower running speed ($P = .019$) and decreased cardiorespiratory endurance ($P = .022$) had a higher incidence of inversion sprains. Results of the analysis performed for isokinetic muscle strength are presented in Table 3. Men with decreased concentric dorsiflexion muscle strength at 30°/s are at greater risk of ankle sprains ($P = .036$).

Figure 1. Survival curve of the students with an ankle sprain.

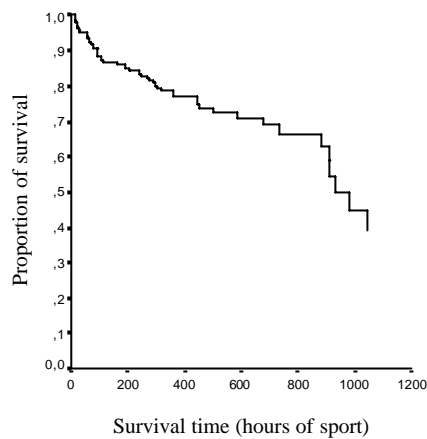


Table 1. Means and standard deviations for demographic data for uninjured and injured subjects

	Uninjured subjects	Injured subjects	P (Cox Regression) ^a
Age, y	18.33 ± 1.18	18.35 ± 0.78	NS
Height, cm	179.88 ± 6.26	180.73 ± 5.71	NS
Mass, kg	69.24 ± 7.19	71.14 ± 5.94	NS
Body mass index	21.37 ± 1.66	21.81 ± 1.71	NS

^aNS, not significant.

Table 2. Means and standard deviations for functional motor performances for uninjured and injured subjects

	Uninjured subjects	Injured subjects	P (Cox Regression)
Flamingo balance	7.57 ± 3.64	9.40 ± 4.95	.001 ^a
Standing broad jump, cm	227.64 ± 21.62	225.92 ± 22.04	NS ^b
Shuttle run, s	19.10 ± 1.09	19.68 ± 1.12	.019 ^a
Endurance shuttle run, min	12.06 ± 1.50	11.13 ± 1.49	.022 ^a

^aSignificant difference between the 2 groups ($P < .05$).

^bNS, not significant.

Table 3. Means and standard deviations for isokinetic concentric and eccentric eversion and inversion muscle strength and concentric plantar flexion and dorsiflexion muscle strength at 30°/s and 120°/s compared to body weight for uninjured and injured subjects^a

	Uninjured subjects	Injured subjects	P (Cox Regression)
EV 30°/s conc/BW	.43 ± .12	.45 ± .14	NS
EV 30°/s ecc/BW	.46 ± .10	.48 ± .14	NS
EV 120°/s conc/BW	.38 ± .10	.39 ± .12	NS
EV 120°/s ecc/BW	.47 ± .10	.49 ± .16	NS
INV 30°/s conc/BW	.54 ± .16	.51 ± .12	NS
INV 30°/s ecc/BW	.56 ± .18	.53 ± .13	NS
INV 120°/s conc/BW	.51 ± .19	.48 ± .17	NS
INV 120°/s ecc/BW	.55 ± .17	.56 ± .16	NS
DF 30°/s conc/BW	.73 ± .30	.54 ± .21	.036 ^b
DF 120°/s conc/BW	.24 ± .09	.25 ± .17	NS
PF 30°/s conc/BW	1.47 ± .38	1.32 ± .36	NS
PF 120°/s conc/BW	.56 ± .26	.65 ± .30	NS

^aExpressed in N.m/kg. EV, eversion; conc, isokinetic concentric; BW, body weight; NS, not significant; ecc, eccentric; INV, inversion; DF, dorsiflexion; PF, plantar flexion.

^bSignificant difference between the 2 groups ($P < .05$).

Table 4 represents the results of the Cox regression, performed for the lower leg alignment characteristics. The analysis showed that men with a decreased dorsiflexion range of motion with the knee straight are at greater risk of ankle sprains ($P = .013$). The results also showed a trend toward a higher extension range of motion at the first metatarsophalangeal joint in men susceptible to ankle sprains ($P = .052$). Results of the Cox regression performed for postural control are presented in Table 5. Ankle injuries were more common among men with decreased directional control ($P = .037$) tested by the limits of stability test. Men with a decreased reaction time in the tibialis anterior muscle ($P = .048$) and the gastrocnemius muscle ($P = .033$) were more likely to sprain their ankle (Table 6). No significant differences were observed between injured and uninjured male subjects for joint position sense.

Table 4. Means and standard deviations for lower leg alignment characteristics for uninjured and injured subjects^a

	Uninjured subjects	Injured subjects	<i>P</i> (Cox Regression)
Talocrural PF	52.39 ± 8.29	52.03 ± 8.64	NS
Talocrural DF (knee extended)	29.25 ± 7.38	25.88 ± 6.52	.013 ^b
Talocrural DF (knee flexed)	34.85 ± 7.59	32.88 ± 6.06	.092
Subtalar INV	18.90 ± 6.49	19.41 ± 8.00	NS
Subtalar EV	10.55 ± 4.58	9.00 ± 5.59	NS
MTPIJ flexion	35.72 ± 10.51	31.97 ± 8.63	NS
MTPIJ extension	67.68 ± 15.17	71.50 ± 15.46	.052
Hip external rotation	38.04 ± 5.18	40.39 ± 6.79	NS
Hip internal rotation	34.56 ± 5.38	33.73 ± 4.67	NS
Position calc unloaded (STJN)	.40 var ± 3.60	.24 valg ± 3.75	NS
Position calc WB (STJN)	1.13 var ± 3.36	2.38 var ± 3.01	NS
Position calc WB	3.03 valg ± 3.04	2.41 valg ± 2.66	NS

^aExpressed in degrees. PF, plantar flexion; NS, not significant; DF, dorsiflexion; INV, inversion; EV, eversion; MTPIJ, metatarsophalangeal I joint; calc, calcaneus; STJN, subtalar joint in neutral position; var, varus alignment; valg, valgus alignment; WB=weightbearing.

^bSignificant difference between the 2 groups ($P < .05$).

Table 5. Means and standard deviations for postural control for uninjured and injured subjects.

	Uninjured subjects	Injured subjects	P (Cox Regression)
Weightbearing, %BW	49.67 ± 4.33	50.10 ± 3.53	NS
Bilat firm EO, °/s	.21 ± .08	.22 ± .07	NS
Bilat EC, °/s	.26 ± .08	.28 ± .09	NS
Bilat foam EO, °/s	.56 ± .11	.59 ± .12	NS
Bilat foam EC, °/s	1.44 ± .35	1.50 ± .38	NS
Unilat EO, °/s	.72 ± .12	.74 ± .16	NS
Unilat EC, °/s	2.47 ± 1.76	2.69 ± 1.23	NS
LOS reaction time, s	.65 ± .20	.60 ± .16	NS
LOS movement velocity, °/s	5.56 ± 1.57	5.61 ± 1.77	NS
LOS directional control, %	79.70 ± 5.57	77.85 ± 6.95	.037 ^b
LOS endpoint excursion, %	80.47 ± 7.62	81.62 ± 9.17	NS
LOS max endpoint excursion, %	90.07 ± 5.04	91.50 ± 6.41	NS
FL distance, % BH	57.69 ± 6.05	57.73 ± 5.28	NS
FL contact time, s	.84 ± .22	.86 ± .21	NS
FL impact index, % BW	30.50 ± 9.67	31.99 ± 11.39	NS
FL force impulse, % BWs	89.59 ± 22.22	91.69 ± 20.90	NS

^aBW, body weight; NS, not significant; Bilat, bilateral stance; firm, firm surface; EO, eyes open; EC, eyes closed; foam, foam surface; unilat, unilateral stance; LOS, limits of stability; max, maximal; FL, forward lunge; BH, body height.

^bSignificant difference between the 2 groups ($P < .05$).

Table 6. Means and standard deviations for muscle reaction time of the peroneus longus, peroneus brevis, tibialis anterior and gastrocnemius muscles for uninjured and injured subjects.

	Uninjured subjects	Injured subjects	P (Cox Regression)
Peroneus longus	83.12 ± 14.12	75.99 ± 10.06	NS ^a
Peroneus brevis	80.40 ± 13.25	73.55 ± 10.90	NS ^a
Tibialis anterior	89.80 ± 11.50	78.67 ± 10.45	.048 ^b
Gastrocnemius	90.31 ± 16.09	79.76 ± 10.66	.033 ^b

^aNS, not significant.

^bSignificant difference between the 2 groups ($P < .05$).

DISCUSSION

In the current study 18% of the 241 students sustained 1 or more inversion sprains; 4 of them had bilateral ankle sprains. This incidence is in agreement with the incidence of 18% lateral ankle sprains observed in male infantry recruits in basic training.⁴¹ Similar ankle injury rates (20.3%) were reported in professional basketball players.⁶² The survival curve of the students with an ankle sprain is shown in Figure 1. Most ankle sprains occur within the first 400 hours of sports participation, as seen by the many downward steps in the curve in this period.

Results of this study revealed no significant relationship between any of the anthropometrical characteristics and the occurrence of inversion sprains. Although a larger mass moment of inertia (mass x height²) has been considered a risk factor for lateral ankle

sprains in recruits,⁴¹ most other studies on ankle sprain risk factors have reported no effect of height or mass on the incidence of ankle sprains.^{3,5,39}

Our results confirm earlier statements that poor physical condition enhances the risk of a sports injury.³⁷ The present investigation identified decreased cardiorespiratory endurance and slower running speed in men who sustain an ankle sprain. Diminished cardiorespiratory endurance could cause earlier fatigue, leading to a less accurate protective effect of the musculature on capsuloligamentous structures. Several other prospective studies on lower extremity injuries have shown a relationship between physical fitness and injury.^{8,21,25,27,55} Therefore, we recommend that primary ankle injury prevention programs should include progressive cardiorespiratory endurance and speed training.

Interestingly, the variable 'general balance', measured by the flamingo balance test showed a significant association with ankle sprains. Our results indicate that male students with a higher score on the flamingo balance test (i.e., a higher number of attempts to keep in balance on the beam for 1 minute) show a higher risk for the development of ankle sprains. Watson⁵⁶ found comparable results in a prospective study on ankle sprain risk factors in male players of the field games Gaelic football and hurling. Surprisingly, we could not identify a predisposing factor in the unilateral balance test on the Neurocom Balance Master. Our results are therefore in contrast to those of other prospective studies,^{38,52} but are in accordance with those of Beynnon et al.⁵ Although the flamingo balance test and the unilateral stance test on the Neurocom Balance Master both measure a variety of sensory input and motor outputs, the flamingo balance test may be a more adequate test for athletes because the task is more difficult. For athletes, keeping balance for only 10 seconds, as in the test on the Neurocom Balance Master, may be too short. Subtle changes may perhaps not manifest during this short period.

However, using the Neurocom Balance Master, we demonstrated that other postural control parameters could predict an ankle injury. Our results show that ankle injuries are more common among men with decreased directional control (limits of stability test). The subject was asked to go directly to the target; thus, a straight-line path to the target is desirable. However, the path to the space target in these subjects is less smooth and continuous, which reflects that the subject's movement coordination is decreased. To reduce the amount of ankle sprains in sports activities, we therefore suggest that balance and coordination training should be included in prevention programs.

Results of this study show no relationship between joint position sense and the risk of an ankle sprain in male athletes. These findings are therefore in contrast to previous findings in basketball teams, where ankle joint proprioceptive deficits were predictive of an ankle injury.⁴⁶ Because few studies have investigated joint position sense as a risk factor for ankle sprains, further research on this topic is needed.

Although it seems obvious that ankle muscle strength is related to the risk of suffering an ankle sprain, only few prospective studies have investigated this, and the findings from these studies differ. Our results show that decreased dorsiflexion muscle strength at 30°/s in men is a risk factor for ankle sprains. We suggest that these subjects cannot accurately perform a dorsiflexion in their ankle when an inversion action occurs. Payne et al.⁴⁶ and Beynnon et al.⁵ could not associate ankle muscle strength with ankle sprains. In contrast, Baumhauer et al.³ found the eversion-to-inversion strength ratio and plantar flexion strength to be significantly greater and the dorsiflexion-to-plantar flexion ratio to be significantly smaller in the injured ankles. In the current study, we found no difference in inversion, eversion or plantar flexion peak torques among athletes who subsequently sustained ankle sprains and those who did not. In addition, none of the calculated ratios was related to subsequent injury. Different results between previous studies and ours can probably be explained by the differences in the methods that were used to analyze the data and the differences in the investigated population. On the basis of our findings, we suggest that dorsiflexion strength training should be included in prevention programs for ankle sprains.

Ankle sprains occur within a time interval that is much faster than that required to develop peak torque during isokinetic testing and at much higher velocities than those used to measure peak torque.⁴ From this perspective, in addition to force, temporal response of the muscles that span the ankle joint should be considered. In this study, we found a significant relationship between a faster muscle reaction time of the tibialis anterior muscle and the gastrocnemius muscle and the occurrence of ankle sprains, which suggests that the protective effect of the leg muscles on joint perturbation may have been compromised. Our results show that in the control group, the peronei - the evertor muscles - provide the first stabilization, followed by the tibialis anterior and the gastrocnemius muscles. In contrast, in men susceptible to ankle sprains, the 4 captured muscles demonstrate almost identical reaction times. Therefore, the accelerated reaction of the tibialis anterior and the gastrocnemius muscles can be considered as an alteration of the musculoskeletal system

that compromises the protective effect of the leg muscles on ankle joint stability. Our results differ from the prospective study of Beynnon et al.⁵, in which no significant relationship was found between muscle reaction times and ankle sprains. On the other hand, many retrospective studies found a relationship between delayed muscle reaction time of the peronei muscles after occurrence of an ankle sprain.^{6,23,44} We recommend that prevention programs should pay attention to the recruitment pattern of the ankle musculature. If possible, exercises should be included to train ankle muscles to adequately react. Further investigation is necessary to elucidate the recruitment patterns of the ankle muscles.

Conspicuous in the present study is the finding of a trend toward a higher extension range of motion at the first metatarsophalangeal joint in subjects susceptible to ankle sprains. This higher extension range of motion at the first metatarsophalangeal joint probably causes a diminished support at this joint during gait. Making the link with kinematics in the unrolling foot, we suggest that foot roll-off does not primarily occur across the hallux as normal but more laterally in subjects who will sustain an ankle sprain.⁵⁸ Because of the diminished support at the first metatarsophalangeal joint, it could be that these subjects, when landing from a jump, also make contact with the ground with the lateral part of the foot instead of with the hallux. This position is very susceptible to inversion sprains⁶¹ and could explain the higher incidence of ankle sprains observed in this study in subjects with a higher extension range of motion at the first metatarsophalangeal joint compared to normal subjects. However, because no kinematic analysis from jumping was carried out in the current study or in previous studies, this finding remains hypothetical and should be investigated further.

Our results indicate that a decreased dorsiflexion range of motion can be considered as a predictive factor of ankle sprains in males. The dorsiflexion range of motion is only significantly decreased in the alignment measurement with the knee straight and not with the knee flexed, which suggests that the gastrocnemius muscle is probably shortened. This shortened musculotendinous unit may place the foot in a position of greater plantar flexion in different sports tasks, increasing the risk of inversion injury. The present investigation supports the earlier findings of Pope et al. in male recruits.⁴⁷ Therefore, we suggest that prevention programs should include strategies such as stretching to increase the dorsiflexion range of motion in the ankle.

One of the limitations of this study is that we only demonstrated an association between ankle inversion sprains and several intrinsic risk factors. Causation still needs to be proven.

CONCLUSION

In this investigation, several measurements of sensorimotor control of the ankle were performed to search for intrinsic risk factors for ankle sprains. Afferent and efferent signals were evaluated. Motor responses were evaluated on the 3 levels of motor control: spinal reflexes (through inversion perturbation of the foot), brain stem activity (through postural control), and cognitive programming (through joint position sense). In addition, static as well as dynamic stabilizers of the ankle joint were investigated. Results of this study show that especially dynamic stabilizers are compromised in men at risk. In summary, this study demonstrated that risk factors that predispose male athletes to ankle ligament injury are slower running speed, less cardiorespiratory endurance, less general balance, less movement coordination, decreased dorsiflexion range of motion, decreased dorsiflexion muscle strength, and decreased reaction time of the tibialis anterior and gastrocnemius muscles. Therefore, to reduce the incidence of ankle sprains, we recommend that prevention programs should include cardiorespiratory endurance, speed, balance, coordination, and dorsiflexion strength training and stretching exercises to increase dorsiflexion range of motion at the ankle.

Acknowledgements

This research was supported by special research grant RUG 01109001. The authors acknowledge Dr. Jan Verstuyft for data collection of injury occurrence.

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CHAPTER 4

INTRINSIC RISK FACTORS FOR INVERSION ANKLE SPRAINS IN FEMALES – A PROSPECTIVE STUDY

**Tine M. Willems¹ PT, Erik Witvrouw¹ PT PhD, Kim Delbaere¹ PT,
Renaat Philippaerts² PE PhD, Ilse De Bourdeaudhuij² PSY PhD,
Dirk De Clercq² PE PhD**

¹ Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, Ghent University, Belgium

² Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, Belgium

Scand J Med Sci Sports, in press, October 2004

Full text online available, DOI:10.1111 /j.1600-0838.2004.00428.x

ABSTRACT

Ankle sprains are extremely common. However, very little is known about the variables that predispose individuals to these injuries. The purpose of this study was to examine prospectively intrinsic risk factors for inversion sprains in a young physically active female population. One hundred and fifty-nine female physical education students were evaluated for several possible intrinsic risk factors for inversion sprains at the beginning of their academic study. The evaluated intrinsic risk factors included anthropometrical and physical characteristics, ankle joint position sense, isokinetic ankle muscle strength, lower leg alignment characteristics, postural control and muscle reaction time during a sudden inversion perturbation. All sports injuries were registered during 1-3 years and exposure to sport was recorded (mean: 15.33 ± 4.33 h a week). Thirty-two (20%) of the 159 females sprained their ankle. The number of ankle sprains per 1000h of sports exposure was 0.75. The Cox regression analysis revealed that females with less accurate passive joint inversion position sense [hazard ratio (HR): 1.08, 95% confidence interval (CI): 1.02-1.14 for absolute error at 15° inversion], a higher extension range of motion at the first metatarsophalangeal joint (HR: 1.03, 95% CI: 1.00-1.06) and less coordination of postural control (HR: 0.96, 95% CI: 0.93-1.00 for endpoint excursion; HR: 0.94, 95% CI: 0.89-0.99 for maximal endpoint excursion) are at greater risk of an ankle sprain. The findings of this study suggest that effective prevention and conservative rehabilitation of ankle inversion sprains should include attention to these variables.

Key words: aetiology, anthropometrical and physical characteristics, proprioception, muscle strength, alignment, postural control, muscle reaction time.

INTRODUCTION

The ankle sprain is one of the most common injuries. In athletes, the lateral ankle complex has been deemed 'the most frequently injured single structure in the body' (Garrick, 1977). In view of the increasing frequency of injury, not only in professional sports but also during leisure-time activities, it is clear that analyses of risk factors for sports injuries are urgently required as a prerequisite to the development of prevention programs (Junge, 2000). Murphy et al. (2003) recently reviewed the literature on the risk factors for lower extremity injuries, demonstrating that our understanding of injury causation is limited. They conclude that more prospective studies are needed, emphasizing the need for proper design and sufficient sample sizes.

Risk factors are traditionally divided into two main categories: intrinsic (person-related) and extrinsic (environment-related) risk factors (Taimela et al., 1990; Van Mechelen, 1992). The intrinsic risk factors are related to the individual characteristics of a person. Extrinsic risk factors relate to environmental variables such as the level of play, exercise load, amount and standard of training, position played, equipment, playing field conditions, rules, foul play, etc. Although ankle sprains are frequently encountered in the sports injury clinic, the causes of this injury remain enigmatic. There are some areas of agreement with regard to extrinsic risk factors (Beynon et al., 2002). However, with regard to the intrinsic risk factors, there is little consensus. One of the most important reasons is probably the lack of good designed prospective investigations set up to determine risk factors for inversion sprains. Therefore, the relationship between intrinsic parameters and ankle sprains remains obscure. With the current emphasis on injury prevention, studies designed to examine potential ankle injury intrinsic risk factors are imperative. Looking at the available literature, several possible intrinsic risk factors for ankle sprains are suggested. Most of the proposed variables have retrospectively been associated with ankle sprains. The proposed variables are: diminished muscle strength (Hartsell & Spaulding, 1999; Munn et al., 2003), diminished postural control (Freeman et al., 1965; Lentell et al., 1990), diminished proprioception (Lentell et al., 1995; Konradsen et al., 1998), malalignment (Shambaugh et al., 1991; Williams et al., 2001), and delayed muscle reaction time (Brunt et al., 1992; Karlsson et al., 1992). However, it is unclear as to whether any of these deficits were present prior to injury, because of the retrospective design of these studies.

The purpose of this investigation was to perform a comprehensive, prospective investigation of the risk factors for inversion sprains. A prospective cohort study was conducted in a young physically active female population. The factors examined include: anthropometrical and physical characteristics, ankle joint position sense, ankle muscle strength, lower leg alignment, postural control and muscle reaction time.

MATERIALS AND METHODS

Subjects

The subjects were 159 female physical education students (age range: 17-26 years; mean age: 18.3 ± 1.1 years), who were freshman in 2000-2001 ($n=53$), 2001-2002 ($n=50$) and 2002-2003 ($n=56$) in Physical Education at the Ghent University, Belgium. All students were tested at the beginning of their education for several possible intrinsic risk factors. Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria were history of a surgical procedure involving the foot or ankle, previous grade II or III inversion ankle sprains, or history of an injury to the lower leg, ankle or foot within 6 months prior to the start of the study. None of the subjects used prophylactic ankle bracing or taping before or during the study.

At university level, the students all followed the same sports program under the same environmental conditions, for 26 weeks per academic year. All students used the same sports facilities and the safety equipment was uniform. The workout program in the first year consisted of $\frac{3}{4}$ h of soccer, handball, basketball and volleyball, 1h of track and field, gymnastics, karate and swimming and 2h of dance every week. In the second year, the weekly workout program consisted of $\frac{1}{2}$ h of climbing, 1h of track and field, soccer, handball, basketball, volleyball, karate and swimming, $1\frac{1}{2}$ h of gymnastics and 2h of dance. In the third year, the program consisted of $\frac{1}{2}$ h of track and field, volleyball, soccer, gymnastics, orienteering and swimming and 1h of handball, basketball, badminton, dance and judo every week. Extramural activities, the amount of physical activities students participate in beyond their sports lessons at school were also registered by means of subjects' completed diary. The mean of the total number of exposure hours of physical activity was 15.33 ± 4.33 h a week.

All volunteers signed an informed consent. The study was approved by the Ethical Committee of the Ghent University Hospital.

The students were followed weekly by the same sports physician for occurrence of injury throughout 3, 2 and 1 academic years for freshman in 2000-2001, 2001-2002 and 2002-2003, respectively. They were asked to report all injuries resulting from sport activities to this physician. All sports injuries sustained during practice, lessons and games were registered by this sports physician. The injury definition was based on that of the Council of Europe (1989). The definition requires that an injury has at least one of the following consequences: (1) a reduction in the amount or level of sports activity, (2) a need for (medical) advice or treatment and (3) adverse social or economic effects. Injury data were recorded on a standardized injury form that captured basic information about type of injury, the circumstances in which the injury occurred and the treatment of the injury.

Instrumentation and protocol

Prior to the start of their physical education, all students were tested for anthropometrical and physical characteristics, joint position sense, muscle strength, lower leg alignment, postural control and muscle reaction time.

Anthropometrical and physical characteristics

The following anthropometrical measurements were evaluated: height (cm), mass (kg), calf girth, humerus and femur width (epicondyle width), and biceps, triceps, subscapular, suprailiac and medial calf skinfolds. Measurements were carried out by the same trained anthropometrist following the procedures as described by Claessens et al. (1990). The body mass indices ($BMI = \text{mass (kg)} / \text{height (m)}^2$), and ponderal indices ($PI = \text{height (m)} / \text{mass (kg)}^{-1/3}$) were calculated. The three somatotype components (endomorph, mesomorph and ectomorph) were calculated using the anthropometric method according to Heath-Carter (Carter & Heath, 1990). Body composition characteristics (fat mass, % fat and fat-free mass, density) were estimated based on the formula of Durnin-Womersley using the Siri equation (Siri, 1956; Durnin & Womersley, 1974).

The physical characteristics, such as general balance, speed of limb movement, flexibility, explosive strength, static strength, trunk strength, functional strength, running speed and cardiorespiratory endurance, were evaluated using the European Test of Physical Fitness. The European Test of Physical Fitness has a good validity and reliability (Council of Europe, 1988). General balance was evaluated by the flamingo-balance test, in which the subject balances on one leg on a beam of set dimensions. The score is the number of

attempts to remain in balance on the beam for one whole minute. The speed of limb movement was tested by rapid tapping of two plates alternately with the preferred hand for 25 cycles. The sit and reach test defined flexibility. Subjects were asked to reach forward as far as possible from a seated position. Explosive strength was measured by a standing broad jump, while static strength was evaluated by the hand-grip test. The maximum number of sit-ups achieved in half a minute defined abdominal strength. Functional strength was measured by the bent arm hang test, in which the subject was asked to maintain a bent arm position while hanging from a bar as long as possible. Running speed was evaluated by a running and turning test of 10 x 5m. The endurance shuttle run test defined cardiorespiratory endurance. All tests were performed with standard equipment and by trained observers, physical therapists and physical educators who were educated to administer the tests.

Ankle joint position sense

Active and passive joint position sense was assessed using the Biodex System 2 Isokinetic Dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA). Each subject was positioned supine on the associated chair, with the calf of the tested leg resting on a 40cm high platform. The barefoot of the subject was aligned with the axis of the dynamometer and attached to the footplate by a very small wrap to reduce cutaneous receptor input. The talocrural joint was in 15° of plantar flexion. The lower leg was secured to the platform by hook-and-loop straps. Three positions were tested: 15° of inversion, maximal active inversion minus 5° and 10° of eversion. Subjects were blindfolded throughout the examination.

For passive testing, the subject's foot was first passively moved by the investigator to maximal eversion (for inversion test positions) or inversion (for eversion test position). The investigator then moved the foot to one of the three test positions, randomly determined. The test position was maintained for 10s. During these 10s, the subject was instructed to concentrate on the position of the foot. The foot was then passively brought to maximal eversion (for the inversion test positions) or to maximal inversion (for the eversion position) and moved passively back toward the other direction with a speed of 5°s⁻¹. The subject was instructed to push a stop button when she thought the test position had been reached. The subject was tested twice at each of the three test positions. The active test was performed in the same manner, except after having the foot passively

placed in the test position and moved to maximal eversion or inversion, the subject was asked to move the foot actively back to the test position. The subject was again asked to push the stop button when she thought the test position was reached. The testing order, test positions and side of the body tested were randomly chosen. The amount of error in degrees was noted for further analysis.

We examined two types of errors in the subjects' ability to match the reference angles: the absolute error and the exact error. Average scores of the two trials were used for analysis. The absolute error was defined as the difference in absolute value in degrees between the position chosen by the subject and the test position angle. The exact error was calculated as the difference between the chosen position and the test position angle and provides an indication of whether the subjects tended to, on average, systematically overshoot (negative exact error) or undershoot (positive exact error) the test position angle (Willems et al., 2002).

Konradsen et al. (2000) validated a comparable method of measuring ankle position sense and found it to be accurate, repeatable and precise.

Muscle strength

A Biodex System 3 Isokinetic Dynamometer and Biodex Advantage Software Package (Biodex Medical Systems, Inc.) were used to determine isokinetic peak torque and peak torque compared to body mass values for reciprocal concentric and eccentric eversion-inversion movements of the ankle and for concentric plantar flexion-dorsiflexion. Positioning for inversion-eversion testing was in a semirecumbent position with 30° of seatback tilt. The ankle was in 10° of plantar flexion. The knee of the tested ankle was in extension to minimize substitution from the hamstrings and other tibial rotators. Dynamometer and chair adjustments were made to align the midline of the foot with the midline of the patella. Positioning for plantar flexion-dorsiflexion was supine with the knee in full extension. In both tests, stabilization was achieved by two straps, wrapped around the extremity proximal to the patella and the pelvis to minimize movements of the hip and knee during testing. Subjects wore their own athletic shoes during testing; each shoe was tightly secured with two straps to the dynamometer footplate to minimize movement between the shoe sole and the footplate surface. The tested range of motion for the inversion-eversion test was maximal active inversion and eversion minus 5° for both directions and for plantar flexion-dorsiflexion maximal active plantar flexion and

dorsiflexion. The first test consisted of three maximal repetitions of concentric-eccentric eversion at 30°s^{-1} to assess the strength of the evertor muscles. The second test for the same ankle consisted of five repetitions of concentric-eccentric eversion at 120°s^{-1} . The same two tests (concentric-eccentric at 30 and 120°s^{-1}) were performed for inversion to assess the strength of the invertor muscles. The same four tests were then performed with the contralateral limb. Next, plantar flexors and dorsiflexors were tested concentrically at 30°s^{-1} (three repetitions) and at 120°s^{-1} (five repetitions). The first tested ankle was randomly chosen. Before data collection, each subject was provided with an opportunity to become familiar with the testing procedure and to perform three warm-up repetitions. Consistent verbal encouragement for maximal effort was given to each subject throughout the testing procedure. None of the subjects felt any discomfort while testing.

Peak torque and peak torque compared with body mass values were obtained for each ankle motion of each limb at the two speeds. Eversion-to-inversion and dorsiflexion-to-plantar flexion strength ratios were calculated.

This protocol for testing plantar flexion-dorsiflexion and inversion-eversion muscle strength was recommended by Dvir (2004) and was found to be reliable (Karnofel et al., 1989).

Lower leg alignment

Lower leg alignment characteristics were determined using goniometric measurements by the same experienced physical therapist. At the talocrural joint, plantar flexion and dorsiflexion range of motion with the knee straight and flexed were measured using the method described by Ekstrand et al. (1982). Inversion and eversion at the subtalar joint and position of the calcaneus, unloaded with the subtalar joint in neutral position were measured. Besides this, the position of the calcaneus was also measured in stance with and without the subtalar joint in neutral position (Elveru et al., 1988). Flexion and extension range of motion at the first metatarsophalangeal joint were also determined. Hip external and internal rotation were measured using the method described by Khan et al. (1997). Talocrural, subtalar and hip goniometric measurements appear to be moderately to highly reliable (Ekstrand et al., 1982; Elveru et al., 1988; Khan et al., 1997). We checked test-retest reliability of the goniometric measurements of the first metatarsophalangeal joint on 12 feet and evaluated intraclass correlation coefficients were between 0.82 and 0.98.

Postural control

Postural control was assessed through five tests using the Neurocom Balance Master (NeuroCom Int. Inc., Clackamas, OR, USA). The first test (weight-bearing) evaluated the percentage of weight borne by each leg. The second test assessed sway velocity of the center of gravity in bilateral positions with eyes open and closed and on a firm and foam surface. Three trials of each test condition were performed, each of which required 10s to perform. The third test evaluated sway velocity in unilateral stance with eyes open and closed. Again, three trials were performed for 10s on both sides. The next test (limits of stability) quantified several movement characteristics associated with the subject's ability to voluntarily sway her center of gravity to various locations in space (forward, right, back and left), and briefly maintain stability at those positions. Subjects were asked to move as quickly and as straight as possible to a specific target. The measured parameters were reaction time, sway velocity, directional control, endpoint excursion (distance at which the initial movement attempt stops or reverses), and maximal excursion (furthest distance the subject reaches on any attempt at the target). The last test (forward lunge) quantified several movement characteristics as the subject lunges forward with one leg, then returns to a standing position. The parameters measured were distance, time, impact index (impact force), and force impuls. The test was repeated three times. A mean value of the three trials was calculated for each condition and was used for analysis.

Reliability of the postural control tests on the Neurocom Balance Master is good to excellent (Van de Vijver & Wynant, 1999)

Muscle reaction time

To measure the muscle reaction time to a sudden inversion perturbation, a specially designed platform that allows each foot to drop into plantar flexion/inversion of 50° from standing in 40° plantar flexion and 15° adduction was used (Vaes et al., 2001). The movement of the platform was recorded by an electrogoniometer and an accelerometer installed on the tilting axis. Prior to electrode application, the skin was shaved, grazed with sandpaper and degreased with alcohol. Surface electromyography (EMG) was used to capture muscle activity of the following muscles: m. peroneus longus, m. peroneus brevis, m. tibialis anterior and the m. gastrocnemius. All electrodes were placed according to the protocol described by Basmajian (Basmajian & De Luca, 1985). The correct placements were verified by particular movements of the foot, causing isolated contractions of the

muscles to be examined, and specific EMG patterns were observed online on the monitor. Telemetric measurements were performed by means of the Myosystem of Noraxon (Noraxon USA, Inc., Scottsdale, AZ, USA). All EMG signals were sampled and analogue to digital (A/D) converted (12-bit resolution) at 1000 Hz.

Each subject was asked to stand in her own sport shoes fixed on the platform with her body mass equally distributed on each foot. Subjects were blindfolded and carried a headphone to eliminate visual and auditory cues to platform release. In random order, five measurements were performed on each side. When EMG signals showed baseline activity, the tilting platform was released. All data were saved on the computer for further analysis. The protocol used has been proven to be satisfactory to highly reproducible (Vaes et al., 2001).

A software package of Myoresearch 2.10 was used for determination of the muscle reaction time. The beginning of the tilting movement by the accelerometer was marked visually. The onset of muscle activity was determined by the first activity after tilting, which took at least 3ms and that was two standard deviations above the baseline activity between the beginning of tilting and 1s before tilting. Average scores of the five trials were used for statistical analysis.

Analysis

SPSS for Windows (version 10.0) was used for statistical analysis. The students were divided into two groups: an uninjured group as a control group (group 1) and a group with subjects who sustained an inversion sprain (group 2). Group 1 consisted of subjects who did not have any injury to either leg in the period they were followed in this study. One of the two uninjured legs was randomly selected, taking into account the percentage of dominant legs in the inversion sprain group. For group 2, data from only the injured legs were used for analysis. A Cox proportional hazard regression was used to test the effect of each variable on the hazard of injury, taking into account differences in the length of time that the athletes were at risk. This approach has been chosen for statistical analysis, because this method can adjust for the fact that the amount of sport participation can vary between the students. The time from the start of the follow-up period until the ankle sprain or the end of follow-up for students that were not injured was the main variable here. Time was measured as the number of hours of sport exposure for each student. This was accomplished by computing time at risk as the total number of hours of sports lessons,

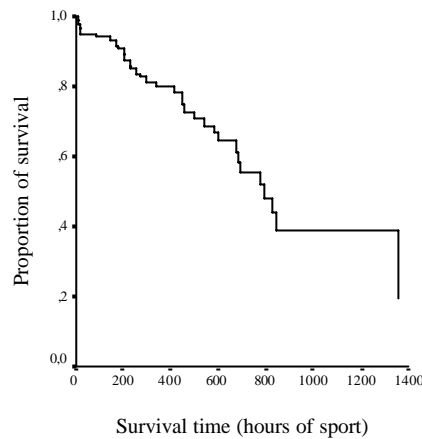
practices for sports lessons, practices for recreational or competition sports and games in which each subject participated until injury or, if uninjured, the end of the period students were followed. This analysis also took censorship into account, such as abbreviated length of follow-up for other reasons than injury (for example, not passing). The method assumes that risk factors affect injury in a proportional manner across time. (Bahr & Holme, 2003)

RESULTS

During the follow-up period, 32 (20%) of the 159 females sprained their ankle. One of the subjects sprained both ankles. Only the initial sprain was used for analysis when repeated sprains occurred. The ankle sprain incidence was 0.75 per 1000h of sports exposure. Only 44 of the 159 subjects (28%) did not sustain any injuries of the lower leg, ankle or foot during the follow-up period. One of their uninjured legs served as the control group.

In 80% of the ankle sprains, the dominant foot was affected. Seventeen (52% of all ankle sprains) ankle sprains were sustained during lessons at the university, one (3%) during practice for lessons, four (12%) during an extramural competition, five (15%) during an extramural training for competition and six (18%) during extramural recreational sports. Eight (24% of all ankle sprains) sprains occurred during gymnastics, four (12%) during basketball, four (12%) during volleyball, three (9%) during soccer, and three (9%) during track and field. The rest of the ankle sprains (33%) happened during other sports, in which the incidence of ankle sprains was low.

Figure 1 displays the survival curve of the students for having an ankle sprain. Anthropometric data on the subjects are listed in Table 1. No significant differences are found between the uninjured group and the ankle sprain group for any of the measured anthropometrical data or for the physical characteristics ($P > .05$). Table 2 represents the results of the Cox regression for the variables of joint position sense with the hazard ratios (HRs) and their 95% confidence interval (CI). Analysis reveal that subjects who show less accurate passive joint position sense at 15° of inversion are at greater risk of ankle sprains ($P = 0.020$ for the exact error, HR: 1.07, 95% CI: 1.01-1.13; and $P = 0.009$ for the absolute error, HR: 1.08, 95% CI: 1.02-1.14). A worse passive joint position sense is also observed in the position of maximal inversion minus 5° in subjects who will sprain their ankle ($P = 0.037$ for the exact error, HR: 1.08, 95% CI: 1.01-1.16; and $P = 0.052$ for the absolute error, HR: 1.09, 95% CI: 1.00-1.18).

Figure 1. Survival curve of the students for having an ankle sprain.**Table 1.** Mean and standard deviation for demographic data for uninjured and injured subjects

	Uninjured	Injured	P-value (Cox regression)
Age (years)	18.39 ± 1.22	18.13 ± 0.49	.499
Height (cm)	167.37 ± 5.19	167.01 ± 5.95	.825
Mass (kg)	60.06 ± 7.11	60.58 ± 7.51	.985
BMI	21.50 ± 2.32	21.81 ± 2.53	.930

BMI, body mass index.

Table 2. Mean and standard deviation for the absolute (abs) and exact (ex) error in degrees for passive (P) and active (A) joint position sense data at the three different test positions, 10° eversion (EV), 15° inversion (INV) and maximal inversion minus 5° (max INV-5°) for uninjured and injured subjects

	Uninjured	Injured	P-value (Cox regression)	Hazard Ratio (95% CI)
Abs P 10° EV	11.10 ± 7.08	12.76 ± 7.74	.379	/
Abs P 15° INV	8.49 ± 5.17	12.41 ± 6.16	.009*	1.08 (1.02-1.14)
Abs P max INV-5°	7.17 ± 4.32	9.26 ± 4.79	.052	/
Abs A 10° EV	4.06 ± 2.73	4.06 ± 2.97	.294	/
Abs A 15° INV	3.97 ± 2.75	3.46 ± 2.95	.843	/
Abs A max INV-5°	3.32 ± 2.39	2.81 ± 1.94	.291	/
Ex P 10° EV	10.74 ± 7.41	12.71 ± 7.80	.307	/
Ex P 15° INV	7.85 ± 5.81	11.81 ± 7.03	.020*	1.07 (1.01-1.13)
Ex P max INV-5°	6.38 ± 5.20	8.85 ± 5.33	.037*	1.08 (1.01-1.16)
Ex A 10° EV	2.23 ± 4.10	0.82 ± 4.76	.176	/
Ex A 15° INV	1.17 ± 4.21	1.31 ± 3.67	.659	/
Ex A max INV-5°	1.09 ± 3.75	1.19 ± 3.03	.350	/

*Significant difference between the two groups ($P < .05$)

CI, confidence interval.

Results of the analysis performed for isokinetic muscle strength are presented in Table 3. Females with increased dorsiflexion muscle strength at 120°s^{-1} are at greater risk of ankle sprains ($P = 0.039$, HR: 756.52, 95% CI: 1.40-408864.14). Table 4 represents the results of the Cox regression, performed for the lower leg alignment characteristics. The results show

that a higher extension range of motion at the first metatarsophalangeal joint increases the risk of an ankle sprain ($P = 0.033$, HR: 1.03, 95% CI: 1.00-1.06).

Table 3. Mean and standard deviation for isokinetic concentric (conc) and eccentric (ecc) eversion (EV) and inversion (INV) muscle strength and concentric plantar flexion (PF) and dorsiflexion (DF) muscle strength at 30°s^{-1} (30) and 120°s^{-1} (120) compared with body weight (BW) for uninjured and injured subjects expressed in Nmkg^{-1} .

	Uninjured	Injured	P-value (Cox regression)	Hazard Ratio (95% CI)
EV 30 conc/BW	.37 ± .09	.36 ± .11	.517	/
EV 30 ecc/BW	.42 ± .11	.41 ± .10	.707	/
EV 120 conc/BW	.32 ± .09	.34 ± .08	.773	/
EV 120 ecc/BW	.42 ± .12	.43 ± .09	.833	/
INV 30 conc/BW	.53 ± .22	.50 ± .22	.374	/
INV 30 ecc/BW	.55 ± .21	.49 ± .18	.832	/
INV 120 conc/BW	.51 ± .21	.45 ± .20	.945	/
INV 120 ecc/BW	.56 ± .20	.50 ± .20	.848	/
DF 30 conc/BW	.71 ± .31	.56 ± .31	.811	/
DF 120 conc/BW	.21 ± .08	.23 ± .07	.039*	NI
PF 30 conc/BW	1.38 ± .38	1.32 ± .36	.642	/
PF 120 conc/BW	.51 ± .29	.63 ± .23	.811	/

*Significant difference between the two groups ($P < .05$)

NI, not interpretable; CI, confidence interval.

Table 4. Mean and standard deviation for lower leg alignment characteristics for uninjured and injured subjects expressed in degrees.

	Uninjured	Injured	P-value (Cox regression)	Hazard Ratio (95% CI)
Talocrural PF	58.34 ± 8.48	58.92 ± 6.51	.880	/
Talocrural DF (knee ext)	30.14 ± 6.39	32.50 ± 8.10	.186	/
Talocrural DF (knee flex)	37.39 ± 6.61	38.19 ± 10.63	.983	/
Subtalar INV	21.75 ± 8.25	20.69 ± 7.30	.475	/
Subtalar EV	9.75 ± 5.35	9.85 ± 5.82	.928	/
MTPIJ flexion	38.27 ± 8.08	39.04 ± 8.66	.846	/
MTPIJ extension	76.48 ± 17.89	83.00 ± 11.37	.033*	1.03 (1.00-1.06)
Hip external rotation	40.57 ± 6.07	40.63 ± 7.00	.101	/
Hip internal rotation	42.05 ± 7.06	44.41 ± 6.17	.263	/
Position calc unloaded (STJN)	.06 valg ± 3.63	.65 valg ± 2.23	.498	/
Position calc WB (STJN)	1.75 var ± 3.11	1.35 var ± 3.49	.489	/
Position calc WB	1.66 valg ± 2.74	2.58 valg ± 3.35	.633	/

PF, plantar flexion; DF, dorsiflexion; ext, extended; flex, flexed; INV, inversion; EV, eversion; MTPIJ, metatarsophalangeal I joint; calc, calcaneus; STJN, subtalar joint in neutral position; var, varus alignment; valg, valgus alignment; WB, weight bearing; CI, confidence interval

*Significant difference between the two groups ($P < .05$)

Results of the Cox regression performed for postural control (Table 5) show that ankle injuries are more common among females with a decreased endpoint excursion ($P = 0.037$, HR: 0.96, 95% CI: 0.93-1.00) and maximal endpoint excursion ($P = 0.020$, HR: 0.94, 95% CI: 0.89-0.99) tested by the limits of stability test. No significant differences are observed between the uninjured group and the ankle sprain group for muscle reaction time.

Table 5. Mean and standard deviation for postural control for uninjured and injured subjects.

	Uninjured	Injured	P-value (Cox regression)	Hazard Ratio (95% CI)
Weight bearing (%BW)	50.50 ± 4.02	49.64 ± 3.52	.203	/
Bilat firm EO (°s ⁻¹)	.22 ± .05	.24 ± .09	.209	/
Bilat EC (°s ⁻¹)	.27 ± .10	.33 ± .29	.152	/
Bilat foam EO (°s ⁻¹)	.51 ± .13	.53 ± .09	.746	/
Bilat foam EC (°s ⁻¹)	1.31 ± .42	1.47 ± .51	.842	/
Unilat EO (°s ⁻¹)	.70 ± .12	.71 ± .14	.605	/
Unilat EC (°s ⁻¹)	2.72 ± 1.82	2.56 ± 1.36	.282	/
LOS reaction time (s)	.66 ± .20	.63 ± .12	.801	/
LOS movement velocity (°s ⁻¹)	5.63 ± 1.80	5.30 ± 1.65	.327	/
LOS directional control (%)	80.25 ± 5.47	79.56 ± 5.40	.742	/
LOS endpoint excursion (%)	87.66 ± 9.77	81.78 ± 11.41	.037*	.96 (.93-1.00)
LOS max endpoint excursion (%)	97.32 ± 5.65	93.30 ± 6.69	.020*	.94 (.89-.99)
FL distance (% BH)	60.95 ± 5.87	58.46 ± 5.61	.080	/
FL contact time (s)	.79 ± .17	.89 ± .24	.096	/
FL impact index (% BW)	28.80 ± 9.41	27.63 ± 7.88	.758	/
FL force impulse (% BW s)	84.77 ± 17.55	94.04 ± 23.94	.078	/

BW, body weight; BH, body height; Bilat, bilateral stance; unilat, unilateral stance; firm, firm surface; foam, foam surface; EO, eyes open; EC, eyes closed; LOS, limits of stability; max, maximal; CI, confidence interval

**Significant difference between the two groups ($P < .05$)*

DISCUSSION

The purpose of this study was to examine intrinsic risk factors for ankle inversion sprains in young physically active females. The results of this study show that less accurate passive joint inversion position sense, increased dorsiflexion muscle strength at 120°s⁻¹, a higher extension range of motion at the first metatarsophalangeal joint and less coordination of postural control were risk factors for an ankle sprain in this population.

In the current study, 32 (20%) of the 159 students sustained one or more inversion sprains, of whom one subject had bilateral ankle sprains. Our 20% ankle sprain incidence in females is in agreement with the incidence of 18% lateral ankle sprains in female professional basketball players (Zelisko et al., 1982). Similar ankle injury rates (19%) were also reported in female collegiate athletes in soccer, lacrosse or field hockey (Beynnon et al., 2001).

The association between limb dominance and ankle sprains is controversial (Beynnon et al., 2002). In our study, 80% of the ankle sprains occurred at the dominant ankle. This finding supports that of Ekstrand and Gillquist (1983) who noted that 92% of the ankle injuries affected the dominant leg in soccer athletes. However, other investigations found no significant relationship between limb dominance and ankle sprains (Surve et al., 1994;

Beynnon et al., 2001). These contrasting findings may have been the result of different study design and differences in sport participation. In certain sports, the dominant leg may be at increased risk of injury because it is preferentially used for kicking, pushing off, jumping or landing. In the current investigation, most of the sprains occurred during gymnastics. In this type of sport participation, the dominant foot is more loaded than the non-dominant.

The results of this study reveal no significant relationship between any of the anthropometrical characteristics and the occurrence of inversion sprains. Although a larger mass moment of inertia (mass x height²) has been considered as risk factor for lateral ankle sprains in recruits (Milgrom et al., 1991), most other studies on ankle sprain risk factors report no effect of height or mass on the incidence of ankle sprains (Baumhauer et al., 1995; Beynnon et al., 2001; McKay et al., 2001).

Several prospective studies on lower extremity injuries have shown a relationship between physical fitness and injury (Chomiak et al., 2000; Kaufman et al., 2000). However, in the current study, no significant relationship could be identified. Most studies that investigated the relationship between physical fitness and injury were performed in male military populations and in male athletes, in contrast to our female population. Beynnon et al. (2001) stated that risk factors are gender dependent. Therefore, we suggest that physical fitness is not a risk factor for inversion ankle sprains in females.

The results of this study show that a worse passive joint position sense at 15° of inversion and at the position of maximal inversion minus 5° increases the risk of an ankle sprain. These findings are in agreement with previous findings in basketball teams (Payne et al. 1997). During this joint position test, neural input is provided through peripheral mechanoreceptors and is not counteracted by visual and vestibular cues and the influence of other joints compared with other neuromuscular control tests as performed by the postural control tests. The test positions that show significant differences in this study associate with the most common mechanism of injury for the ankle: inversion and plantar flexion. It has been frequently suggested that inversion sprains may occur as a result of improper positioning of the foot before and at foot contact (Wright et al. 2000; Willems et al., 2002). However, in an earlier prospective study on ankle sprains (Willems et al., 2004), no kinematic changes at foot contact in running could be identified, although, at foot contact, a trend toward a more laterally situated center of pressure was seen in subjects who will sustain an inversion sprain. According to this, the results of the current study

demonstrate that females susceptible to ankle sprains have an altered afferent input, demonstrated by a worse passive ankle joint position sense. Because of the altered proprioception at the ankle, an inappropriate foot positioning as a more laterally situated center of pressure, could occur and could result in spraining the ankle. On the basis of our findings, we therefore suggest that proprioception training should be included in prevention strategies for ankle sprains.

Although it seems obvious that ankle muscle strength is related to the risk of suffering an ankle sprain, only few prospective studies have investigated this and the findings from these studies differ. Payne et al. (1997) and Beynnon et al (2001) could not associate ankle muscle strength with ankle sprains. However, Baumhauer et al. (1995) found the eversion-to-inversion strength ratio to be significantly greater in the injured group compared with the uninjured group. They also found that the injured ankles had higher plantar flexion strength and a smaller dorsiflexion-to-plantar flexion ratio compared with the contralateral uninjured ankle. In the current study, we found no difference in inversion, eversion or plantar flexion peak torques among athletes who subsequently sustained ankle sprains and those who did not. In addition, neither the ratio between ankle eversion and inversion peak torque values, nor the ratio between dorsiflexion and plantar flexion peak torque values related to subsequent injury. The Cox regression analysis showed a significant association between ankle sprains and increased dorsiflexion muscle strength at 120°s^{-1} . However, we are not able to find a simple explanation for this finding. As the dorsiflexion muscle strength at 30°s^{-1} is not significantly different between the groups and as the HR and the 95% CI show extremely high and unrealistic values, which makes it difficult to interpret them, we suggest that dorsiflexion muscle strength is not of importance in the aetiology of ankle sprains.

Very conspicuous in this present study is the finding that a higher extension range of motion at the first metatarsophalangeal joint significantly increases the risk of an ankle sprain in females. This higher extension range of motion at the first metatarsophalangeal joint probably causes a diminished support at the first metatarsophalangeal joint during gait. Making the link with kinematics in the unrolling foot, we suggest that through this, foot roll-off does not primarily occur across the hallux as normal, but more laterally in subjects who will sustain an ankle sprain (Willems et al., 2004). Because of the diminished support at the first metatarsophalangeal joint, it could be that these subjects, when landing from a jump, also make contact with the ground with the lateral part of the foot instead of

with the hallux. This position is very susceptible for inversion sprains (Wright et al., 2000) and could explain the higher incidence of ankle sprains in subjects with a higher extension range of motion at the first metatarsophalangeal joint observed in this study compared with normal subjects. However, as no kinematic analysis from jumping was carried out in the current study or in previous studies, this remains hypothetical and should be investigated further.

Other alignment characteristics such as inversion, eversion, dorsiflexion and plantar flexion range of motion could not to be related to the risk of suffering an ankle sprain among female physical education students. These results are partly in contrast to the results of previous studies (Baumhauer et al., 1995; Beynnon et al., 2001), since a higher calcaneal eversion range of motion has been related to suffering ankle ligament traumas in women (Beynnon et al., 2001) and in athletes as a group (Baumhauer et al., 1995). Differences in results between previous studies and this study can probably be explained by the differences in the methods used to measure eversion range of motion. In the study of Baumhauer et al. (1995) and Beynnon et al. (2001), calcaneal eversion was measured relative to the subtalar neutral position, while we measured the subtalar eversion as the angle between the midline of the lower leg and the calcaneus.

We could not identify a predisposing factor in the unilateral balance test on the Neurocom Balance Master. Our results therefore differ of those of other prospective studies (Tropp et al., 1984; McGuine et al., 2000), but are in accordance with those of Beynnon et al. (2001). However, using the Neurocom Balance Master we demonstrated that other postural control parameters can predict an ankle injury. Our results show that ankle injuries are more common among females with a decreased endpoint excursion and maximal endpoint excursion tested by the limits of stability test. This reflects that these females are less able to move their center of gravity accurately. This finding shows that women with decreased movement coordination are more likely to sustain ankle sprains. In order to reduce the amount of ankle sprains in sports activities, we therefore suggest that coordination training should be included in prevention programs.

Ankle sprains occur within a time interval that is much faster than that required to develop peak torque during isokinetic testing and at much higher velocities than those used to measure peak torque (Beynnon et al., 2002). From this perspective, besides the force, temporal response of the muscles that span the ankle joint should also be considered. In this study, we could not find a significant relationship between the muscle reaction times

of the mm. peronei, the m. tibialis anterior and the m. gastrocnemius and ankle sprains. Our results are in accordance with those of Beynnon et al. (2001), who also could not find a significant relationship between muscle reaction times and ankle sprains.

The present investigation is one of few prospective investigations conducted on the risk factors for inversion sprains. As the aetiology of ankle sprains is multifactorial, in which several factors can play a significant role, we have attempted to study as many potential intrinsic risk factors as possible. Therefore, in this investigation, a number of methods to measure sensorimotor control of the ankle have been used to search for risk factors of ankle sprains. Afferent and efferent signals have been evaluated. Motor responses have been evaluated on the three levels of motor control: spinal reflexes (through inversion perturbation of the foot), brain stem activity (through postural control) and cognitive programming (through joint position sense). In addition, static as well as dynamic stabilizers of the ankle joint have been investigated. However, a limitation in our study is therefore the large amount of variables in our analysis, which increases the risk for significances and decreases the power. Future research on larger populations is recommended to affirm our findings. Another limitation in our study is that we did not take the type and intensity of physical activity into consideration. In our analysis, we only took the amount of physical activity into account. As type and intensity are both important extrinsic risk factors, future research could take these variables into account.

Perspectives

In summary, this study has demonstrated that the risk factors that predispose a female athlete to ankle ligament injury are less accurate passive joint inversion position sense, less coordination of postural control and a higher extension range of motion at the first metatarsophalangeal joint. These findings should be considered in preventive strategies in order to reduce the amount of ankle sprains. The identified risk factors are modifiable and therefore, ankle injuries could probably be decreased with proper interventions. Given the size of the problem, a systematic process of prevention should be initiated with routine surveillance to identify high-risk subjects. Properly planned interventions should then be implemented with the expectation of reduced incidence of ankle sprains. Intervention strategies should therefore focus on increasing ankle joint inversion position sense and coordination and by limiting the extension range of motion of the first metatarsophalangeal

joint. We also suggest that conservative rehabilitation programs should pay attention to these variables.

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CHAPTER 5

RELATIONSHIP BETWEEN GAIT BIOMECHANICS AND INVERSION SPRAINS: A PROSPECTIVE STUDY OF RISK FACTORS

**Tine M. Willems¹ PT, Erik Witvrouw¹ PT PhD, Kim Delbaere¹ PT,
Anneleen De Cock² PE, Dirk De Clercq² PE PhD**

¹ Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, Ghent University, Belgium

² Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, Belgium

Gait Posture, in press, May 2004

Full text online available, DOI:10.1016/j.gaitpost.2004.04.002

Winner of the 'Best Paper Award 2003'

by the European Society for Movement Analysis in Children and Adults

ABSTRACT

This prospective study determined gait related risk factors for inversion sprains in 223 physical education students. Static lower leg alignment was determined, and 3D-kinematics combined with plantar pressure profiles was collected. After evaluation, the same sports physician registered all sports injuries during the next 6-18 months. During this period, 21 subjects had an inversion sprain, one of whom had a bilateral sprain. Twenty-two ankles, 12 left and 10 right comprised the inversion sprain group and both feet of 36 non-injured subjects acted as controls. Comparison of the two groups revealed that the gait of subjects who are at risk of sustaining an inversion sprain had a laterally situated centre of pressure at initial contact. These subjects also showed a mobile foot type at first metatarsal contact, forefoot flat and heel off. In this type the foot is more pronated over a prolonged period and accompanied by more pressure underneath the medial side of the foot and a delayed maximal knee flexion. Resupination is delayed and roll off does not occur across the hallux, but more laterally, probably because of the diminished support at the first metatarsophalangeal joint. Total foot contact time was also longer in the inversion sprain group compared with controls. The findings of this study suggest that effective prevention and rehabilitation of inversion sprains should include attention to gait patterns and adjustments of foot biomechanics.

Key words: ankle sprain, risk factors, plantar pressure, kinematics, alignment

INTRODUCTION

Lateral ankle sprain is a very common athletic injury but little is known about predisposing factors and only a few prospective studies have investigated the underlying risk factors.¹⁻⁴ Knowledge of the aetiology of ankle sprains is relevant for prevention and rehabilitation. The aetiology of inversion sprains is most probably multifactorial.⁵ Intrinsic risk factors may include age, joint instability, muscle strength, muscle tightness, muscle strength asymmetry, previous injuries, adequacy of rehabilitation, psychosocial stress, and gait. Extrinsic risk factors relate to environmental variables such as the level of sporting expertise, exercise load (amount of competition and practice), amount and standard of training, position played, equipment, playing field conditions, rules, and foul play. Both intrinsic and extrinsic factors can influence each other and are therefore not independent of each other.⁶⁻⁸

It has been assumed that biomechanical abnormalities in gait are one of the causes of inversion sprains and accurate positioning of the foot at touchdown is very important in gait and sports. It has been frequently hypothesized that contacting the ground in an increased inversion position could result in an ankle sprain.^{9,10} A plantar flexed position of the ankle at touchdown, as well as an inverted position of the foot, are potential factors for an ankle sprain, because the ground reaction force moment arm about the subtalar joint increases.¹⁰⁻¹² Thus we hypothesized that increased pressure at the lateral border of the heel at touchdown may also be an underlying cause of an ankle sprain. As the centre of pressure (COP) can be interpreted as a moment arm for the vertical ground reaction force,¹³ a laterally situated COP may result in an ankle sprain.

In a recent prospective study, increased calcaneal eversion range in women and increased talar tilt in men have been shown as risk factors for ankle sprains.⁴ We hypothesized that these alignments would affect gait and could be indicative of a mobile foot type, which allows more eversion during stance.

A static foot type has been investigated as a possible risk factor for ankle sprains, but differing results have been found. Dahle et al.¹⁴ and Barrett et al.¹⁵ found no correlation between foot type and ankle sprains whereas Williams et al.¹⁶ reported a higher incidence of ankle sprains in individuals with a high arch.

Despite the belief that many factors play a role in the development of ankle sprains no prospective studies have been undertaken to determine the role of dynamic gait related risk

factors. Therefore, the purpose of this prospective study was to determine gait related risk factors for inversion sprains in a physically active population.

METHODS

Subjects

Two hundred and twenty-three physical education students who were freshman in 2001-2002 (93 students) and 2002-2003 (130 students) at the Ghent University in Belgium were evaluated (age: 18.3 years \pm 1.0; height: 174.5 cm \pm 8.4; body mass: 65.1 kg \pm 8.6). Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria were history of an injury to the lower leg, ankle or foot within six months before the start of the study. The Ethical Committee of Ghent University Hospital approved the study and all volunteers gave informed consent. Before the start of their academic study, 3D kinematic, plantar pressure and lower leg alignment data were collected.

The same sports physician registered all sports injuries during a year and a half for the first group and during six months for the second group. Injury data were recorded on a standardised injury form that included information about the type, mechanism and treatment of the injury.

Instrumentation

Plantar pressure data, 3D-kinematic data and lower leg alignment data were collected. A footscan pressure plate (RsScan International, 2m x 0.4m, 16384 sensors, 480 Hz) was mounted flush in the middle of a 16.5 m long wooden running track upon a 2 m AMTI-force platform. Video data were collected at 240 Hz using seven infrared cameras (Proreflex) and Qualisys software. Marker placement was based on that of McClay and Manal.^{17,18} Retro-reflective markers were placed on the thigh, the lower leg and the rearfoot. The anatomical markers were placed on the greater trochanter, the medial and lateral femoral condyles, the medial and lateral malleolus, the medial and lateral part of the calcaneus and on the head of the first and fifth metatarsals. The tracking markers consisted of a rigid plate secured to the thigh and the shank and the medial, lateral and upper markers on the calcaneus.

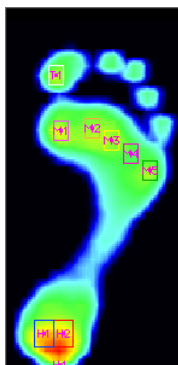
Following a standing calibration trial, the subjects were asked to run barefoot at a speed of 3.3 m/s within a boundary of 0.17 m/s. All subjects were allowed to familiarise themselves with the procedures before data collection. Three valid left and three valid right stance phases were measured. A trial was considered to be valid when the following criteria were met: a heel strike pattern, running speed within the outlined boundaries, no adjustment in step length or step frequency to aim on the pressure plate.

Static lower leg alignment characteristics comprised plantar and dorsiflexion range at the talocrural joint, inversion and eversion range at the subtalar joint, flexion and extension range at the first metatarsophalangeal joint (MTPJ 1), hip internal and external rotation and position of the calcaneus in stance.

Data analysis

For each trial, eight anatomical pressure areas were identified by the researcher, based on the peak pressure footprint (Fig. 1; Footscan software 6.3.4 mst, RsScan international). These areas were defined as medial heel (H_1), lateral heel (H_2), metatarsal heads I – V (M_1 , M_2 , M_3 , M_4 and M_5) and the hallux (T_1) (heel areas: 2.1 x 1.5 cm; metatarsal areas and hallux: 1.4 x 1.0 cm).

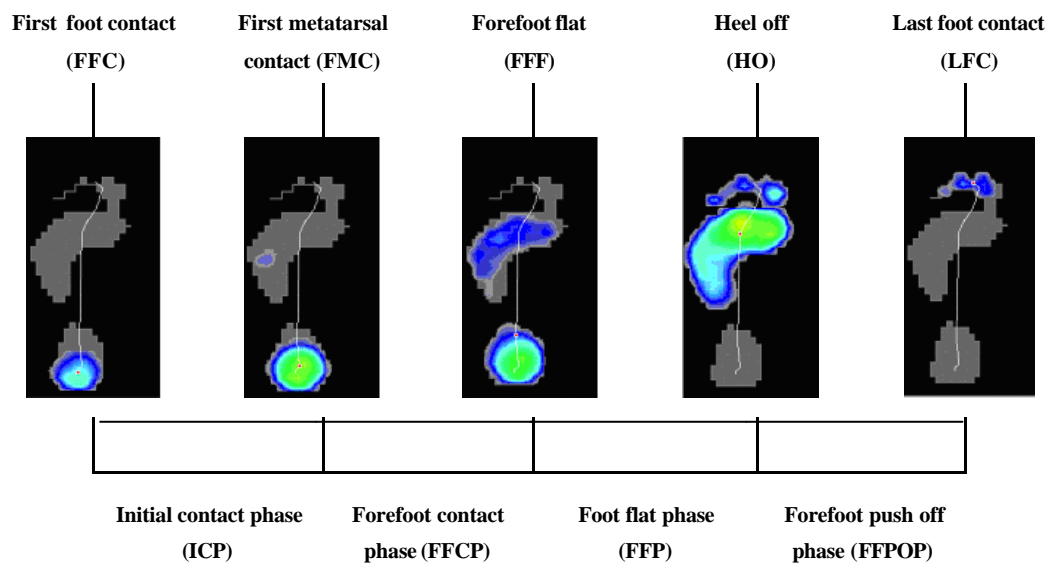
Figure 1. The location of eight anatomical important areas on the peak pressure footprint. (Footscan software 6.3.4 mst, RsScan International)



Temporal data (i.e. time to peak pressure, instants on which the regions make contact and instants on which the regions end foot contact), peak pressure data and absolute impulses (mean pressure x loaded contact time) and relative impulses (absolute impulse x 100 / sum of all impulses) were calculated for all eight regions. As well as the total foot contact time, five distinct instants of foot rollover were determined for each trial. These were: first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel off (HO) and last

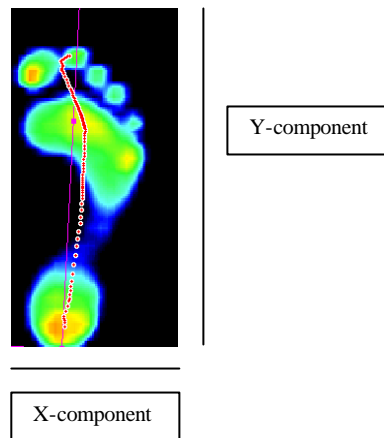
foot contact (LFC). FFC was defined as the instant the foot made first contact with the pressure plate. FMC was defined as the instant when one of the metatarsal heads contacted the pressure plate. FFF was defined as the first instant all metatarsal heads made contact with the pressure plate. HO was defined as the instant the heel region lost contact with the pressure plate. LFC was defined as the last contact of the foot on the plate. Based on these instants, total foot contact could be divided into four phases: initial contact phase (ICP; FFC ? FMC), forefoot contact phase (FFCP; FMC ? FFF), foot flat phase (FFP; FFF ? HO) and forefoot push off phase (FFPOP; HO ? LFC) (Fig. 2). Two medio-lateral pressure ratios were calculated at these five instants of the foot contact (Ratio 1 = $[(H_1+M_1+M_2)-(H_2+M_4+M_5)]/\text{sum of pressure underneath all areas}$; Ratio 2 = $(M_1-M_5)/\text{sum of pressure underneath all metatarsal heads}$). Ratio 1 describes the pressure distribution in the whole foot and ratio 2 the pressure distribution in the forefoot. Excursion ranges of these ratios were calculated over the four phases (ICP, FFCP, FFP, FFPOP).

Figure 2. Five distinct instants and phases relative to total foot contact



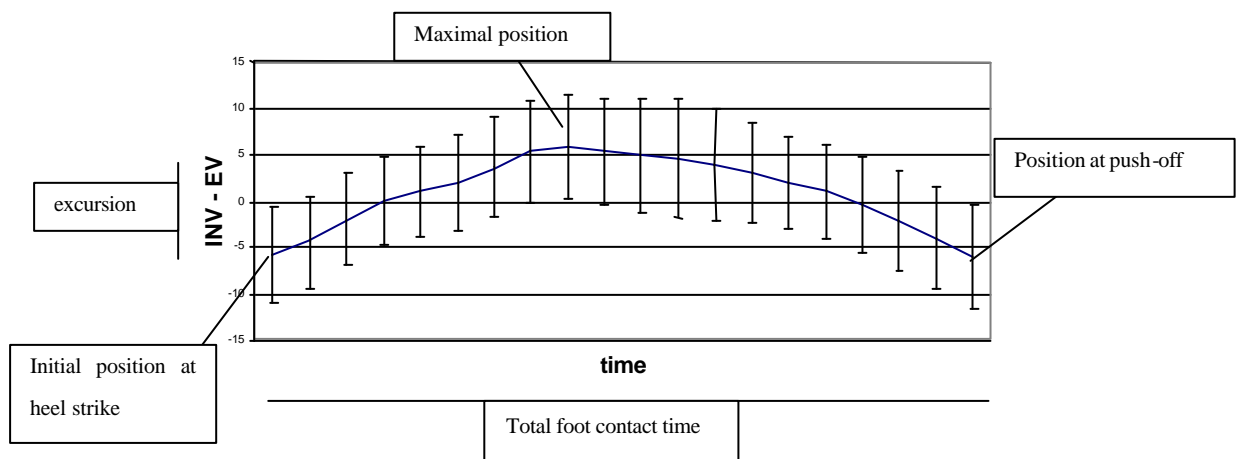
The X-component (medio-lateral) and Y-component (anterior-posterior) of the COP scaled to the foot width and foot length, respectively, were analysed (Fig. 3). The positioning and displacements of the components were calculated at the five instants and in the four phases.

Figure 3. The X-component (medio-lateral) and Y-component (anterior-posterior) of the centre of pressure. The X-component is positive when it is positioned medially of the heel-M2 axis and negative when it is laterally positioned.



A multi-segment model was developed to calculate 3D joint coordinate system angles (Visual 3D, S.Selbie, USA). The three-dimensional motions of the knee and the ankle were investigated through positioning of the segments with respect to each other: rearfoot with respect to a laboratory coordinate system, rearfoot to lower leg and lower leg with respect to the thigh. Joint rotation was calculated around the medio-lateral, the sagittal and frontal axes. All angles were referenced to standing. This study focused on the stance phase during running. Therefore, from the kinematic data, initial position at heel-strike, position at push-off, maximal position, relative time to maximal position, excursion, maximal and mean velocity and time to maximal velocity were identified for rearfoot with respect to a laboratory frame, rearfoot to shank and shank with respect to thigh (Fig. 4).

Figure 4. Indication of the identified kinematic variables (total foot contact time, initial position at heel strike, position at push-off, maximal position and excursion) on the mean curve for inversion-eversion movement of the rearfoot with respect to the lower leg as example.



The mean of all kinetic and kinematic data was taken from the three trials. Previous research has shown that the mean of three trials is sufficient for analysis.^{19,20}

Statistical analysis

During the injury registration period, 21 subjects (13 male and eight female) had an inversion sprain; one subject had a bilateral sprain. The inversion sprain group comprised 22 ankles (12 left and 10 right ankles). As control group, both feet of 36 uninjured subjects were selected out of the group of subjects who were followed for 18 months. This avoided the inclusion of subjects who were still at risk of an ankle sprain. None of these 36 subjects (23 male and 13 female) had any lower extremity injury.

SPSS for Windows (version 10.0) was used for statistical analysis. A binary logistic regression analysis²¹ was performed to identify the intrinsic risk factors for inversion sprains. Student's *t*-tests (if the distributions of the data were normal) or Mann-Whitney *U*-tests (if no normal distribution of the data was obtained) were undertaken firstly to reduce the number of variables. All variables showing a *P*-value < 0.1 in the univariate analysis were entered separately into the logistic regression analysis. A significance level of $\alpha = .05$ was used for the logistic regression analysis.

RESULTS

Logistic regression analysis revealed that the absolute impulse underneath M_1 was significantly higher ($P = .050$) and the relative impulse underneath M_5 was significantly lower ($P = .039$) in the inversion sprain group. No significant differences were found between the two groups for the peak pressure underneath the eight anatomical areas. Mean and standard deviation for peak pressure, absolute impulse and relative impulse underneath the eight anatomical areas are shown in Table 1. Analyses revealed that total contact time was significantly longer in the inversion sprain group compared to controls ($P = .017$). Through logistic regression, no significant differences were found between the two groups for the other temporal pressure data (Table 2). The medio-lateral ratios (Table 3) show that pressure distribution was more medially directed at first metatarsal contact (ratio 2, $P = .004$), forefoot flat (ratio 1, $P = .038$; ratio 2, $P = .022$) and heel off (ratio 1, $P = .040$; ratio 2, $P = .049$) in the inversion sprain group. Furthermore, medio-lateral ratios showed less displacement of the pressure from lateral to medial in the initial contact phase (ratio 2, $P =$

.002) and forefoot contact phase (ratio 1, $P = .027$; ratio 2, $P = .020$). In the forefoot push off phase, there was significantly more pressure displacement from medial to lateral (ratio 1, $P = .035$; ratio 2, $P = .049$).

Values for the X-component of the COP are shown in Table 4. The X-component of the COP is situated significantly more laterally at last foot contact ($P = .012$) and COP displaces more laterally in the forefoot push off phase ($P = .004$) in the inversion sprain group. No significant differences are found for the Y-component of the COP.

Table 1. Mean and standard deviation for peak pressure, absolute impulse and relative impulse underneath the eight anatomical areas.

	Mean control group	SD control group	mean inversion sprain group	SD inversion sprain group	Significance t -test, MW U -test	Significance logistic regression
PMaxT1 (N/cm ²)	39.77	17.82	37.08	23.62	.569	/
PMaxM1 (N/cm ²)	50.35	21.38	60.62	32.17	.087	.103
PMaxM2 (N/cm ²)	58.95	15.48	62.87	22.05	.353	/
PMaxM3 (N/cm ²)	49.71	11.44	50.60	10.69	.747	/
PMaxM4 (N/cm ²)	39.02	13.13	36.13	8.07	.333	/
PMaxM5 (N/cm ²)	38.35	17.08	30.81	15.37	.067	.072
PMaxH1 (N/cm ²)	90.69	27.39	82.01	24.74	.188	/
PMaxH2 (N/cm ²)	83.46	28.71	75.78	26.47	.267	/
AbsImpulsT1 (Ns/cm ²)	3.36	1.83	3.09	2.15	.568	/
AbsImpulsM1 (Ns/cm ²)	4.74	1.97	6.09	3.61	.026*	.050*
AbsImpulsM2 (Ns/cm ²)	6.40	1.75	7.37	2.89	.149	/
AbsImpulsM3 (Ns/cm ²)	5.29	1.25	5.69	1.46	.211	/
AbsImpulsM4 (Ns/cm ²)	3.89	1.30	3.77	0.98	.681	/
AbsImpulsM5 (Ns/cm ²)	3.43	1.62	2.81	1.49	.112	/
AbsImpulsH1 (Ns/cm ²)	2.33	0.84	2.51	1.05	.409	/
AbsImpulsH2 (Ns/cm ²)	1.97	0.85	1.95	0.92	.936	/
RelImpulsT1 (%)	10.66	5.32	8.94	5.16	.185	/
RelImpulsM1 (%)	15.21	5.99	17.80	7.93	.106	/
RelImpulsM2 (%)	20.37	4.84	22.14	6.80	.180	/
RelImpulsM3 (%)	16.85	3.17	17.36	4.56	.551	/
RelImpulsM4 (%)	12.31	3.27	11.60	3.55	.384	/
RelImpulsM5 (%)	10.89	4.41	8.59	4.33	.034*	.039*
RelImpulsH1 (%)	7.41	2.44	7.58	3.11	.786	/
RelImpulsH2 (%)	6.29	2.68	5.99	2.77	.649	/

(PMax: maximal peak pressure, AbsImpuls: absolute impulse, RelImpuls: relative impulse). Significance level for t -test or Mann-Whitney U -test (MW U -test) and significance level for logistic regression analysis.

* Significant difference between the two groups ($P < .05$)

Table 2. Mean and standard deviation for total contact time, time of first metatarsal contact (FMC), forefoot flat (FFF) and heel off (HO), relative first contact time and relative end of contact to total foot contact for the eight anatomical regions.

	mean control group	SD control group	mean inversion sprain group	SD inversion sprain group	Significance <i>t</i> -test MW <i>U</i> -test	Significance logistic regression
Total contact time (s)	.217	.017	.228	.019	.013*	.017*
FMC (s)	.018	.009	.017	.009	.619	/
FFF (s)	.039	.011	.038	.014	.551	/
HO (s)	.094	.020	.103	.020	.086	/
First contact T1 (%)	31.06	9.76	32.23	8.99	.618	/
First contact M1 (%)	17.83	5.37	15.27	5.12	.050*	.055
First contact M2 (%)	15.04	3.58	13.42	4.64	.088	.092
First contact M3 (%)	12.48	3.66	10.91	4.25	.094	.098
First contact M4 (%)	9.85	3.91	8.40	4.18	.138	/
First contact M5 (%)	8.34	4.17	8.46	5.08	.915	/
First contact H1 (%)	0.02	0.06	0.00	0.00	.265	/
First contact H2 (%)	0.01	0.05	0.00	0.00	.439	/
End contact T1 (%)	97.67	4.36	98.25	2.33	.553	/
End contact M1 (%)	90.17	4.49	90.69	3.35	.616	/
End contact M2 (%)	93.31	3.99	94.05	3.33	.436	/
End contact M3 (%)	90.97	4.23	91.15	4.74	.868	/
End contact M4 (%)	84.38	4.52	83.79	5.60	.609	/
End contact M5 (%)	74.97	4.63	73.56	5.55	.237	/
End contact H1 (%)	42.96	7.82	44.41	7.79	.451	/
End contact H2 (%)	39.62	8.73	41.50	8.47	.378	/

Significance level for *t*-test or Mann-Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis. * Significant difference between the two groups ($P < .05$)

Table 3. Mean and standard deviation of the medio-lateral ratios at the five instants (first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel off (HO) and last foot contact (LFC)) and in the four phases of the stance phase (initial contact phase (ICP), forefoot contact phase (FFCP), foot flat phase (FFP) and forefoot push off phase (FFPOP)).

	mean control group	SD control group	mean inversion sprain group	SD inversion sprain group	Significance <i>t</i> -test MW <i>U</i> -test	Significance logistic regression
Ratio 1 FFC	-.141	.378	-.113	.377	.770	/
Ratio 1 FMC	-.007	.226	-.010	.233	.961	/
Ratio 1 FFF	-.212	.210	-.096	.250	.033*	.038*
Ratio 1 HO	.068	.211	.173	.169	.036*	.040*
Ratio 2 FMC	-.776	.267	-.538	.384	.011*	.004*
Ratio 2 FFF	-.318	.141	-.220	.212	.013*	.022*
Ratio 2 HO	.026	.160	.103	.137	.043*	.049*
Ratio 1 ICP	.135	.197	.104	.193	.522	/
Ratio 1 FFCP	-.205	.202	-.086	.236	.022*	.027*
Ratio 1 FFP	.280	.197	.268	.225	.821	/
Ratio 1 FFPOP	-.016	.288	-.159	.177	.030*	.035*
Ratio 2 ICP	-.769	.268	-.514	.400	.009*	.002*
Ratio 2 FFCP	.457	.227	.318	.251	.016*	.020*
Ratio 2 FFP	.344	.172	.323	.131	.602	/
Ratio 2 FFPOP	-.026	.160	-.103	.137	.043*	.049*

Significance level for *t*-test or Mann-Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis. Ratio 1 = $[(H1+M1+M2)-(H2+M4+M5)]/\text{sum of the pressure underneath all areas}$; Ratio 2 = $(M1-M5)/\text{sum of pressure underneath all metatarsal heads}$. A positive ratio indicates a medially directed pressure distribution, a negative ratio a laterally directed pressure distribution

* Significant difference between the two groups ($P < .05$)

Table 4. Mean and standard deviation for the scaled X-component (medio-lateral) of the centre of pressure in percentage of foot width at the five instants (first foot contact (FFC), first metatarsal contact (FMC), forefoot flat (FFF), heel off (HO) and last foot contact (LFC)) and in the four phases (initial contact phase (ICP), forefoot contact phase (FFCP), foot flat phase (FFP) and forefoot push off phase (FFPOP)).

	mean control group	SD control group	mean inversion sprain group	SD inversion sprain group	Significance <i>t</i> -test MW <i>U</i> -test	Significance logistic regression
X-comp FFC	-1.95	1.86	-2.75	2.84	.062	.138
X-comp FMC	-1.14	3.20	-2.00	3.65	.286	/
X-comp FFF	-9.24	6.88	-7.84	6.06	.392	/
X-comp HO	-10.21	6.65	-8.30	5.59	.225	/
X-comp LFC	8.37	7.59	2.99	9.77	.008*	.012*
X-comp ICP	0.81	2.11	0.75	1.99	.907	/
X-comp FFCP	-8.11	5.93	-5.83	5.97	.120	/
X-comp FFP	-0.97	5.04	-0.46	5.08	.682	/
X-comp FFPOP	18.55	8.85	11.29	11.03	.002*	.004*

The X-component is positive when it is positioned medially of the heel-M2 axis and negative when it is positioned laterally (Fig. 3). Significance level for *t*-test or Mann-Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

* Significant difference between the two groups ($P < .05$)

Table 5 shows the mean values and standard deviations for the kinematic data of the rearfoot with respect to the laboratory frame in the frontal plane. Kinematic data show that the instant of maximal inversion velocity occurred significantly later in the inversion sprain group ($P = .050$). The timing of maximal knee flexion was significantly delayed ($P = .032$), and the mean knee flexion velocity is significantly lower ($P = .002$) (Table 6).

Table 5. Mean and standard deviation for kinematic data of the rearfoot with respect to the laboratory frame for the sagittal axis (inversion-eversion) (RelTime: relative time to total foot contact, Vel: velocity)

	mean control group	SD control group	mean inversio n sprain group	SD inversio n sprain group	Significance <i>t</i> -test MW <i>U</i> -test	Significance logistic regression
Initial eversion position (°)	-8.78	4.04	-8.90	3.31	.913	/
Max eversion (°)	-0.87	4.34	0.56	4.25	.117	/
Excursion eversion (°)	8.56	3.82	10.23	4.17	.063	.129
Pushoff eversion (°)	-10.68	3.97	-10.96	6.11	.822	/
RelTime Max eversion (%)	44.73	14.72	51.52	16.17	.054	.110
Max eversion Vel (°/s)	240.34	110.71	301.19	152.94	.105	/
Max inversion Vel (°/s)	-236.44	82.31	-264.67	120.69	.265	/
RelTime Max eversion Vel (%)	18.19	10.68	23.14	18.04	.153	/
RelTime Max inversion Vel (%)	81.90	18.73	91.99	6.13	.000*	.050*
Mean eversion Vel (°/s)	72.06	43.11	75.07	37.62	.797	/
Mean inversion Vel (°/s)	-83.19	39.25	-100.83	53.62	.137	/

Significance level for *t*-test or Mann-Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

* Significant difference between the two groups ($P < .05$)

Table 6. Mean and standard deviation for kinematic data of the lower leg with respect to the upper leg for the medio-lateral axis (flexion-extension in the knee)

	mean control group	SD control group	mean inversion sprain group	SD inversion sprain group	Significance <i>t</i> -test MW <i>U</i> -test	Significance logistic regression
Initial flexion position (°)	12.64	6.34	11.62	7.39	.586	/
Max flexion (°)	43.64	6.22	42.50	6.09	.507	/
Excursion flexion (°)	31.00	4.43	30.42	4.97	.652	/
Push off flexion (°)	20.17	6.55	17.46	7.14	.146	/
RelTime Max flexion (%)	44.20	4.75	47.54	6.51	0.021*	.032*
Max flexion Vel (°/s)	617.70	147.56	600.93	166.84	.699	/
RelTime Max flexion Vel (%)	18.02	6.39	16.63	7.49	.450	/
Mean flexion Vel (°/s)	285.01	39.01	245.69	27.64	0.000*	.002*

(*RelTime*: relative time to total foot contact, *Vel*: velocity) Significance level for *t*-test or Mann-Whitney *U*-test (MW *U*-test) and significance level for logistic regression analysis.

* Significant difference between the two groups ($P < .05$)

Alignment measurements showed that subjects in the inversion sprain group, had a significantly higher MTPJ I extension range of motion ($P = .021$; $78.25^\circ \pm 13.71$ versus $67.33^\circ \pm 16.52$ for the control group).

A Bonferroni correction was not applicable as all the variables that were evaluated in this study were strongly correlated. Altman et al. have recommended that unadjusted *P*-values should be reported.²²

DISCUSSION

To date, no investigations for gait related variables as possible risk factors for ankle sprains have been performed. There have been some prospective studies on other intrinsic risk factors of ankle sprains e.g. generalized joint laxity, isokinetic muscle strength, ankle proprioception, anatomic alignment of the foot and ankle and muscle reaction time.^{2,4} However, in overuse injuries of the lower leg, foot biomechanics are an important intrinsic risk factor.^{23,24} We suggest that the mechanisms for the unrolling foot during stance phase could be important in the development of ankle sprains as well.

Our results demonstrate that the gait of subjects who will sustain an inversion sprain has typical characteristics. These can be summarised as follows: 1) a longer total foot contact time, 2) a higher loading underneath the medial and less loading underneath the lateral border of the foot, 3) a medially directed pressure distribution at first metatarsal contact, forefoot flat and heel off and less pressure displacements in the intervening phases, 4) a delayed knee flexion, 5) a more laterally directed pressure displacement in the forefoot

push off phase and a laterally situated COP at last foot contact, and finally 6) a greater extension range of motion at the MTPJ I.

In contrast to our hypothesis of an increased inversion or plantar flexed foot position at initial contact, the results of this study show no kinematic differences at initial contact between the control and the inversion sprain group. However, muscle model driven computer simulations have shown an increased touchdown plantar flexion which has been shown to cause an increased likelihood of an ankle sprain.¹⁰ Spaulding et al.²⁵ observed in a retrospective study that chronically unstable ankles were more plantar flexed at foot contact compared to stable control ankles. In the plantar flexed position, the ankle is less stable than in the neutral or dorsiflexed position (close packed position) because of the anteriorly wedge-shaped structure of the talus. A frequent question in retrospective studies is whether the findings are the result or the cause of the injury. We did not find a limited dorsiflexion range or an increased touchdown plantar flexion in our subjects and hypothesize that after an ankle sprain there is a limited dorsiflexion range. This concurs with Spaulding et al.²⁵ and it seems that this lack of dorsiflexion contributes to a more plantar flexed position at initial contact. We suggest that an increased touchdown plantar flexion could therefore be considered as a consequence of an ankle sprain rather than a cause.

Many investigations have indicated that proprioception is disturbed after an ankle sprain.²⁶⁻²⁹ An inappropriate positioning of the ankle may also be due to the loss of proprioceptive input from mechanoreceptors.

As hypothesized, the results of this study show a trend toward a laterally situated COP at first foot contact in the inversion sprain group. This implies that the trust needed to invert the ankle is smaller in these subjects. It is possible that, while walking or running on uneven ground, ankles at risk of a sprain are less able to accommodate changes in the surface as well as controls can. Becker et al.³⁰ measured plantar pressure distribution during gait in subjects with functional and mechanical ankle instability. They found a significantly higher impulse underneath the lateral side of the heel in subjects with functionally unstable ankles. In mechanically unstable ankles, they did not find any differences in the heel region. When considering peak pressures and impulses at the heel in the current study, no significant differences between controls and the inversion sprain group were found even though the medio-lateral component of the COP is situated more laterally at first heel contact. These findings are probably due to methodological differences.

In the study of Becker et al.³⁰, the heel region was divided into three areas in contrast to the present study, where only two areas were defined.

Data from the present study show that loading underneath the medial side of the foot is higher and lower underneath the lateral border in subjects who will sustain an inversion sprain. This can be seen through 1) the absolute impulse underneath M_1 , which was significantly higher, 2) the relative impulse underneath M_5 , which was significantly lower, 3) the medio-lateral ratios, which indicate that pressure distribution was more medially directed at first metatarsal contact, forefoot flat and heel off and 4) less displacement of the pressure from lateral to medial in the initial contact phase and the forefoot contact phase. Kinematic data showed that there was a trend of a higher eversion excursion in the rearfoot. There was also a trend toward a delayed maximal eversion of the rearfoot. Biomechanically, there is no direct correlation between inversion sprains and an increase in medial loading. However, there is probably an indirect correlation and we suggest that the inversion sprain group have dynamic mobile feet. Although, no significant differences were found between the two groups for static inversion and eversion range of motion at the subtalar joint as in the study of Beynnon et al.,⁴ mobility at the midtarsal joints was not investigated. A possible explanation could be that subjects have an unstable feeling due to their mobile feet and try to unroll their feet more medially as a compensation to avoid lateral ankle sprains. This would cause more pressure underneath the medial side of the foot and is accompanied with more eversion.

In addition the relative contact of M_1 was earlier in the inversion sprain group. Even though M_1 was earlier in contact with the ground, peak pressure underneath M_1 occurred later. To explain these findings, it could be possible that the inversion sprain group had a hyper-mobile first ray. However, the mobility of the first ray was not measured in this study.

At the knee, maximal flexion occurred significantly later in the inversion sprain group and mean knee flexion velocity was significantly smaller. This delayed knee flexion corresponded to the delayed maximal eversion of the foot. This phenomenon relates to the related timing of movement and coupling mechanism between the knee and the subtalar joint.³¹

Kinematic results also showed that maximal resupination velocity is significantly delayed in the rearfoot in the inversion sprain group. This probably occurs because of the prolonged pronation phase and so resupination has to occur in a shorter time. Furthermore,

the X-component of the COP was significantly more laterally situated at last foot contact and the COP was more displaced laterally in the forefoot push off phase. Hence medio-lateral ratios also showed more lateral pressure displacement in the forefoot push off phase. This suggests that roll off does not occur across the hallux, but more laterally, across the lesser toes. This is probably caused by the diminished support at the MTPJ I, which had a very mobile extension range of motion compared to the control group.

Ankle sprains are not solely related to running but also occur during lateral cutting and side-shuffle movements and landing from a jump. When landing from a jump, first contact is made with the toes and the same roll off pattern occurs in the opposite direction as in running. Because of the diminished support at the MTPJ I, it could be that the inversion sprain group also make contact with the ground with the lateral toes instead of with the hallux when landing from a jump. This plantar flexed position is very susceptible for inversion sprains.¹⁰ However, this aspect was not investigated in the present study and is an area for future investigation.

Total foot contact time was also longer in the inversion sprain group compared to normal subjects. Therefore, only relative times to the total foot contact time were taken into consideration. A possible explanation for the longer stance phase is the longer time when the foot was everted.

We focused on the movements of the rearfoot, as in most previous biomechanical studies,^{17,18,32-34} and one of the limitations in our study was the lack of kinematics and alignment measurements of the midfoot and forefoot. However, plantar pressure measurements are very suitable to quantify the interaction between the different foot structures and the ground during stance phase.³⁵

The findings of this study suggest that effective prevention and rehabilitation of inversion sprains should include attention to gait patterns and adjustments of the foot biomechanics in subjects at risk of a sprain. However, clinical assessment after an ankle sprain does not normally include a gait pattern analysis. Ankle taping and bracing have been shown to reduce the incidence of respraining³⁶ and may be effective in preventing a first sprain. De Clercq³⁷ has shown that bracing reduces the range of subtalar eversion while running in normal subjects. Wearing a brace could result in a reduction of the mobility of the foot and a more even distribution of the plantar pressure that could give more stability in susceptible subjects. Foot orthotic devices to give better support could also be prescribed to reduce the amount of extension range of motion in the MTPJ I.

Acknowledgements

This research was supported by BOF-RUG 01109001. The authors acknowledge Dr. Jan Verstuyft for data collection of injury occurrence, Ing. Pierre Van Cleven for technical support in data collection of plantar pressure and kinematics and Friso Hagman for model building.

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CHAPTER 6

A PROSPECTIVE STUDY TO GAIT RELATED RISK FACTORS FOR EXERCISE- RELATED LOWER LEG PAIN

**Tine M. Willems¹ PT, Dirk De Clercq² PE PhD, Kim Delbaere¹ PT,
Guy Vanderstraeten¹ MD PhD, Anneleen De Cock² PE, Erik Witvrouw¹ PT PhD**

¹ Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, Ghent University, Belgium

² Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, Belgium

Gait & Posture, in press, December 2004

ABSTRACT

The purpose of this study was to determine prospectively gait related risk factors for exercise-related lower leg pain (ERLLP) in 400 physical education students. Static lower leg alignment was determined, and 3D gait kinematics combined with plantar pressure profiles were collected. After this evaluation, all sports injuries were registered by the same sports physician during the duration of the study. Forty six subjects developed ERLLP and 29 of them developed bilateral symptoms thus giving 75 symptomatic lower legs. Bilateral lower legs of 167 subjects who developed no injuries in the lower extremities served as a controls. Cox regression analysis revealed that subjects who developed ERLLP had an altered running pattern before the injury compared to the controls and included 1) a significantly more central heel strike, 2) a significantly increased pronation, accompanied with more pressure underneath the medial side of the foot, and 3) a significantly more lateral roll-off. These findings suggest that altered biomechanics play a role in the genesis of ERLLP and thus should be considered in prevention and rehabilitation.

Keywords: shin splints, stress fractures, plantar pressure, kinematics, alignment

INTRODUCTION

Exercise-related lower leg pain (ERLLP) is a common and enigmatic overuse problem in athletes and military populations.¹ Runners, track athletes and athletes participating in jumping sports are frequently diagnosed with ERLLP which is usually induced by repetitive tibial strain imposed by loading during intensive, weight bearing activities. A variety of categories can be labelled under this broad terminology of ERLLP and includes pathologies or terms such as shin splints, shin pain, medial tibial stress syndrome (MTSS), periostitis, compartment syndrome and stress fractures. However, the term ERLLP will be used in this paper as used by Brukner², as it adequately describes the clinicopathological features of the condition, while remaining appropriate for each term.

Generally, the most effective treatment for ERLLP is considered to be rest, often for prolonged periods.¹ This will significantly disrupt an active lifestyle, and sometimes end activity-related careers entirely. Therefore, analyses of risk factors for ERLLP are required as a prerequisite to the development of prevention programs.

Murphy et al.³ recently reviewed the literature on risk factors for lower extremity injuries and demonstrated that our understanding of injury causation is limited. They concluded that more prospective studies are needed, emphasising the need for proper design and sufficient sample sizes. In the literature, several aetiological factors have been suggested to induce ERLLP, which include in isolation or in combination, changes in training, activity type, intensity and frequency, footwear, and terrain as extrinsic (environmental related) risk factors.^{1,4} As intrinsic risk factors, lack of running experience, poor physical condition, previous injury, decreased muscle strength, muscle fatigue, inflexibility, malalignment and adverse biomechanics have been quoted.^{1,4,5} Retrospective studies have noted excessive dynamic foot pronation in subjects with a history of ERLLP.^{6,7} In addition, static foot posture in subjects with ERLLP also showed a pronated foot alignment.⁸⁻¹⁰

However, cross-sectional studies only allow clinicians to establish relationships but longitudinal prospective studies can investigate cause and effect relationships. Hitherto, no studies have been published on dynamic biomechanical intrinsic risk factors of ERLLP prospectively. The purpose of this prospective cohort investigation was to determine gait related risk factors for ERLLP in a young physically active population.

MATERIALS AND METHODS

Subjects

The subjects were 400 physical education students (241 men, 159 women; age range: 17-28 years; mean age: 18.4 ± 1.1 years), who were freshman in 2000-2001 (n=121), 2001-2002 (n=133) and 2002-2003 (n=146) in Physical Education at the Ghent University, Belgium. All signed informed consent and the Ethical Committee of the Ghent University Hospital approved the study. Gait pattern and static alignment of the students were evaluated at the beginning of their education. Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria included a history of a surgical procedure involving the lower leg, ankle or foot, or history of an injury to the lower leg, ankle or foot within six months before the start of the study.

At the university level, the students followed the same sports program (Table 1) under the same environmental conditions, for 26 weeks per academic year. All students used the same sports facilities and the safety equipment was uniform. Extramural activities, being the amount of physical activities students participate in beyond their sports lessons at school were also registered.

Table 1. Weekly sports program in hours for physical education students at the Ghent University.

	1 st year	2 nd year	3 rd year
Soccer	¾	1	½
Handball	¾	1	1
Basketball	¾	1	1
Volleyball	¾	1	½
Track and field	1	1	½
Gymnastics	1	1 ½	½
Karate	1	1	-
Swimming	1	1	½
Dance	2	2	1
Climbing	-	½	-
Orienteering	-	-	½
Badminton	-	-	1
Judo	-	-	1

The students were followed weekly by the same sports physician for occurrence of injury throughout three, two and one academic years for freshman in 2000-2001, 2001-2002 and 2002-2003 respectively. They were asked to report all injuries resulting from sports activities during practice, lessons and games to this physician. The injury definition was based on that of the Council of Europe¹¹, which requires that an injury has at least one of

the following consequences: 1) a reduction in the amount or level of sports activity, 2) a need for (medical) advice or treatment or 3) adverse social or economic effects. All injuries were medically assessed by the physician. When the diagnosis was not clear through this clinical assessment, x-ray, echography, bone scintigraphy (for diagnosis of stress fractures) or intracompartmental pressure measurement (for diagnosis of compartment syndrome) were performed.

Instrumentation and protocol

Before the start of their physical education, all students were tested for 3D kinematics combined with plantar pressure measurements during running and static lower leg alignment characteristics.

A footscan pressure plate (RsScan International, 2m x 0.4m, 16384 sensors, 480 Hz) was mounted flush in the middle of a 16.5 m long wooden running track upon a 2m AMTI-force platform. Video data were collected at 240 Hz using seven infrared cameras (Proreflex) and Qualisys software. Marker placement was based on that of McClay and Manal^{12,13} (Figure 1). This particular orientation enables the markers to define the anatomical coordinate system and to be used to track the motion of the segments.¹² Following a standing calibration trial, the subjects were asked to run barefoot at a speed of 3.3 m/s within a boundary of 0.17 m/s. After familiarisation, three valid left and three valid right stance phases were measured. A trial was considered as valid when the following criteria were respected: a heel strike pattern, running speed within the outlined boundaries, and no visual adjustment in gait pattern to contact the pressure plate. Raw marker positioning was filtered with a second order, bidirectional low-pass Butterworth filter with padding point extrapolation with the reflected method. The cut off frequency was 18Hz for the markers of the foot and the lower leg and 6Hz for the markers of the thigh.

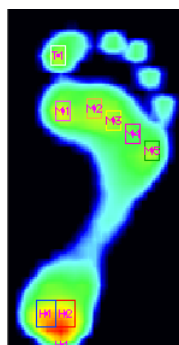
For each trial, eight anatomical pressure areas were semi-automatically identified, based on the peak pressure footprint (Figure 2). These areas were medial heel (H_M), lateral heel (H_L), metatarsal heads I – V (M_1 , M_2 , M_3 , M_4 and M_5) and the hallux (T_1) (heel areas: 2.1 x 1.5 cm; metatarsal areas and hallux: 1.4 x 1.0 cm). Peak pressure data, impulses (mean pressure x loaded contact time) and instants on which the regions make contact and end foot contact relative to total foot contact time were calculated for all eight regions. For each trial, besides the total foot contact time, five distinct instants of foot rollover were determined: first foot contact (FFC, instant the foot makes first contact with the pressure

plate), first metatarsal contact (FMC, instant one of the metatarsal heads contacts the plate), forefoot flat (FFF, first instant all metatarsal heads make contact with the plate), heel off (HO, instant the heel region loses contact with the plate) and last foot contact (LFC, last contact of the foot on the plate).¹⁴ Based on these instants, total foot contact could be divided into four phases: initial contact phase (ICP; FFC? FMC), forefoot contact phase (FFCP; FMC? FFF), foot flat phase (FFP; FFF? HO) and forefoot push off phase (FFPOP; HO? LFC).¹⁴ A medio-lateral pressure ratio was calculated at these five instants of the foot contact ($\text{Ratio} = \frac{(H_M + M_1 + M_2) - (H_L + M_4 + M_5)}{\text{sum of pressure underneath all areas}}$).¹⁵ Excursion range of this ratio was calculated over the four phases.

Figure 1. Marker placement based on that of McClay and Manal.^{12,13} Retroreflective markers were placed on the upper and lower leg and on the rearfoot. The anatomical markers were placed on the greater trochanter, the medial and lateral femoral condyle, the medial and lateral malleolus, the medial and lateral part of the calcaneus and on the first and fifth metatarsal heads. The tracking markers consisted of a rigid plate secured to the thigh and the shank and the medial, lateral and upper calcaneus markers.

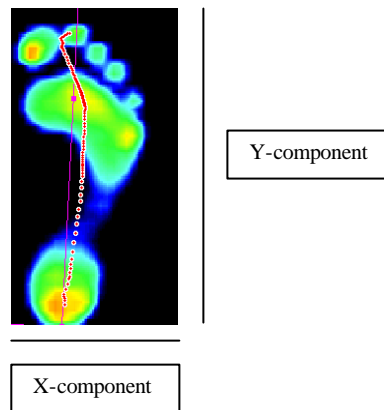


Figure 2. The location of eight anatomical important areas on the peak pressure footprint. (Footscan software 6.3.4 mst, RsScan International)^{14,15}



The X-component (medio-lateral) and Y-component (anterior-posterior) of the centre of pressure (COP) scaled to the foot width and foot length respectively were analysed (Figure 3). The positioning and displacements of the components were calculated respectively at the five instants and during the four phases.

Figure 3. The X-component (medio-lateral) and Y-component (anterior-posterior) of the COP. The X-component is positive when it is positioned medially of the heel-M2 axis and negative when it is laterally positioned. The X-component and Y-component were scaled to the foot width and foot length respectively. Foot width and foot length were defined on a separate static blueprint of the foot at the metatarsal heads and from heel to the furthest-reaching toe respectively.¹⁵



A multi-segment model was developed to calculate 3D joint coordinate system angles (Visual 3D, C-motion, USA). The three-dimensional motions of the knee and the ankle were investigated through positioning the lower leg segment with respect to the upper leg and the rearfoot with respect to the lower leg respectively. Joint rotation was calculated around the plantar-dorsiflexion, inversion-eversion, abduction-adduction axes for the ankle and the flexion-extension, varus-valgus, internal-external rotation axes for the knee. All angles were referenced to standing. This study focused on the stance phase during running. Therefore, from the kinematic data, initial position at heel-strike, position at push-off, maximal position, excursion, maximal and mean excursion velocity were identified. From all kinetic and kinematic data, mean of the three discrete variables of interest was calculated. Previous research has shown that for interpreting these data analysing the mean of three trials is sufficient.^{14,16,17}

Static lower leg alignment characteristics comprised manual goniometric talocrural plantar and dorsiflexion range with the knee straight and flexed¹⁸, subtalar inversion and eversion¹⁹, position of the calcaneus, unloaded and with the subtalar joint in neutral

position and in stance with and without the subtalar joint in neutral position and flexion and extension range of motion at the first metatarsophalangeal joint.¹⁹ Talocrural and subtalar goniometric measurements appear to be moderately to highly reliable.^{18,20} Test-retest reliability of the goniometric measurements of the first metatarsophalangeal joint was good (intraclass correlation coefficients between .82 and .98 evaluated on twelve feet).

Analysis

Statistics were performed using SPSS (version 11.0). The students were divided into two groups: an injury group with the injured legs of subjects who developed ERLLP and a control group of 167 subjects who did not have any injury of either leg during this study. Subjects who developed other injuries than ERLLP (n=187) were excluded from the comparison. Firstly, a univariate Cox proportional hazard regression was used to test the effect of each variable on the hazard of injury, taking into account differences in the length of time that the subjects were at risk. Secondly, variables showing statistically significant association ($P < .05$) in the first analysis were entered into a multivariate forward stepwise Cox regression analysis to obtain a model for the prediction of ERLLP. This approach has been chosen because Cox regression can adjust for the fact that the amount of sport participation can vary between subjects. The primary outcome was the time from the start of the follow-up period until the first symptoms of ERLLP or the end of follow-up for students that were not injured. Time at risk was measured for each student as the total number of hours of sport exposure during sports lessons, practices for sports lessons, practices for recreational or competition sports and games until injury or, if uninjured, the end of the period students were followed. This analysis also took censorship into account, such as abbreviated length of follow up for other reasons than injury (for example, not passing their academic course). The method assumed that risk factors affected injury in a proportional manner across time.²¹

RESULTS

During this study, 46 (11.5%, 17 males and 29 females) of the 400 subjects developed ERLLP. Twenty-nine developed bilateral symptoms. Consequently, the injury group comprised 75 symptomatic lower legs (35 left and 40 right). Figure 4 displays the survival curve of the students for developing ERLLP.

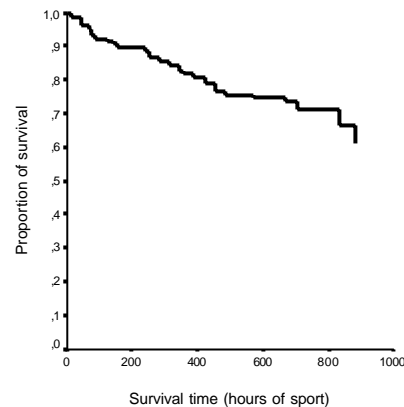
Figure 4. Survival curve of the students for having exercise-related lower leg pain.

Table 2 summarizes the significant results from the univariate Cox regression analysis. From all measured alignment characteristics, only extension range of motion at the first metatarsophalangeal joint was significantly different between groups. Analysis revealed that subjects who showed a higher extension range at the first metatarsophalangeal joint were at greater risk of ERLLP ($P = .002$).

Analysis of the pressure data showed that maximal peak pressure and impulse underneath M_5 is decreased in the injury group ($P = .006$ and $P = .011$ respectively). In the injury group, relative time of making contact was delayed in H_L ($P = .006$) and in M_5 ($P = .033$) and relative time of end of contact was delayed in M_2 ($P = .005$) and M_3 ($P = .032$). The medio-lateral pressure ratio showed that a higher pressure underneath the medial side of the foot at forefoot flat ($P = .003$) and heel off ($P = .049$) and a greater displacement of the pressure from lateral to medial in the forefoot contact phase ($P = .001$) increased the risk of ERLLP. Analysis of the medio-lateral component of the COP revealed that subjects with a more medially directed COP at forefoot flat ($P = .039$) and a more laterally directed COP at last foot contact ($P < .001$) were at greater risk of ERLLP. During the forefoot contact phase there was less displacement of the COP to lateral ($P = .001$) and during the forefoot push off phase there was more displacement to lateral in subjects susceptible to ERLLP ($P < .001$). Subjects who showed an increased distance of the anterior-posterior component of the COP at initial contact ($P = .007$) and a decreased distance at last foot contact ($P = .001$) were at greater risk of ERLLP.

Results of the Cox regression performed for 3D kinematics at the ankle showed that subjects of the ERLLP group had a significantly increased abduction excursion ($P = .026$) and accordingly increased maximal abduction velocity ($P = .001$), an increased maximal eversion ($P = .034$) and eversion excursion ($P = .032$) and accordingly increased mean and

maximal eversion velocity ($P = .034$ and $P = .031$ respectively). Mean re-inversion velocity ($P = .029$) was also increased in these subjects. No significant differences were observed between the two groups for 3D kinematics at the knee joint.

Table 2. Mean and standard deviation for significant contributors for exercise-related lower leg pain by univariate Cox regression analysis for uninjured and injured subjects.

	Uninjured	Injured	P-value
MTPIJ extension	70.89 ± 16.95	76.64 ± 15.22	.002
Peak pressure M ₅ (N/cm ²)	34.86 ± 18.85	26.88 ± 13.19	.006
Impulse M ₅ (Ns/cm ²)	3.14 ± 1.82	2.41 ± 1.34	.011
First contact H _L (%)	.00 ± .04	.04 ± .13	.006
First contact M ₅ (%)	9.12 ± 5.87	11.34 ± 10.43	.033
End contact M ₂ (%)	93.76 ± 3.82	95.38 ± 3.54	.016
End contact M ₃ (%)	91.29 ± 4.44	92.91 ± 4.13	.032
Ratio FFF	-10.30 ± 24.10	1.54 ± 29.04	.003
Ratio HO	14.12 ± 18.56	20.16 ± 18.28	.049
Ratio FFCP	-9.77 ± 21.66	2.39 ± 26.12	.001
X-comp FFF (%)	-7.98 ± 6.91	-5.49 ± 4.66	.039
X-comp LFC (%)	10.30 ± 8.77	3.23 ± 8.59	< .001
X-comp FFCP (%)	-6.80 ± 5.81	-3.54 ± 4.55	.001
X-comp FFPOP (%)	18.71 ± 9.37	10.99 ± 8.54	< .001
Y-comp FFC (%)	8.45 ± 1.80	9.31 ± 5.36	.007
Y-comp LFC (%)	93.87 ± 4.45	91.28 ± 6.37	.001
Excursion abduction (°)	11.43 ± 4.02	12.92 ± 4.88	.026
Max abduction Vel (°/s)	353.66 ± 119.17	435.01 ± 173.52	.001
Max eversion position (°)	7.66 ± 5.05	9.60 ± 5.81	.034
Excursion eversion (°)	13.81 ± 4.39	15.47 ± 5.46	.032
Mean eversion Vel (°/s)	114.92 ± 48.92	133.34 ± 54.87	.034
Max eversion Vel (°/s)	381.28 ± 141.43	440.73 ± 195.42	.031
Mean inversion Vel (°/s)	140.57 ± 76.03	173.56 ± 75.37	.029

MTPIJ=metatarsophalangeal I joint, FFF=forefoot flat, HO=heel off, FFCP=forefoot contact phase, LFC=last foot contact, Vel=velocity

Ratio=[(H_M+M₁+M₂)-(H_L+M₄+M₅)]x100/sum of the pressure underneath all areas; a positive ratio indicates a medially directed pressure distribution, a negative ratio a laterally directed pressure distribution.

Table 3 represents the risk model ($P < .001$) for the prediction of ERLLP as a result of a multivariate stepwise Cox regression analysis. The anterior-posterior component of the COP at first foot contact ($P = .087$), the medio-lateral ratio during the forefoot contact phase ($P = .007$) and the medio-lateral component of the COP at last foot contact ($P < .001$) were found to be the best predictors of ERLLP.

Table 3. Risk model for the prediction of exercise-related lower leg pain versus no injury obtained by multivariate Cox regression.

	B	SE	P-value	Hazard Ratio	95% Confidence Interval
Y-comp FFC	.081	.047	.087	1.084	.988-1.189
Ratio FFCP	3.762	1.400	.007	43.047	2.769-669.275
X-comp LFC	-.134	.038	<.001	.874	.811-.942

FFC= first foot contact, FFCP=forefoot contact phase, LFC=last foot contact
B=regression coefficient, SE=standard error

DISCUSSION

The present investigation is the first study to determine dynamic biomechanical intrinsic risk factors of ERLLP prospectively. The overall incidence of ERLLP reported in our population (11.5%) is comparable with previous reports.^{8,22} The increased incidence in women (18% versus 7% in men) is in accordance with other studies.^{8,10} This study reveals that the running pattern of subjects who develop ERLLP differed from subjects who remained injury free. Summarized, these altered biomechanics include: 1) a central heel strike at initial contact, 2) a more everted foot accompanied with a higher loading underneath the medial forefoot and less underneath the lateral forefoot during the forefoot contact and foot flat phases, and 3) an increased re-inversion velocity with an increased lateral roll-off and increased extension range of motion at the first metatarsophalangeal joint.

Kinematic variables and plantar pressure data showed the same trends of excessive eversion and an increased lateral roll-off in the running pattern of the subsequently injured subjects. Although plantar pressure variables were more discriminating between the injured and uninjured subjects, we chose for a functional division concerning content in which plantar pressure was combined with kinematic data and alignment.

The pathophysiology of medial tibial stress syndrome remains controversial. Some authors suggest an inflammation of the periosteum due to excessive traction (traction theory), others support the view that MTSS is not an inflammatory process of the periosteum, but rather a bone stress reaction (bone stress theory) as in stress fractures.²³⁻²⁵ Although that MTSS and stress fractures constitute different pathologies, they sometimes coexist and it is likely that MTSS and stress fractures of the tibia are invoked by similar mechanisms, where MTSS is a relatively mild expression and stress fracture is a severe extreme.¹ The coincidence of the most common site of tibial stress fracture at or near the junction of the middle and distal thirds with the site of incidence of MTSS bolsters this suspicion.¹

The most striking result of this investigation was that an increased eversion increased the risk for ERLLP, which can be functionally linked with both theories. Several kinematic and plantar pressure parameters indicate this increased loading underneath the medial side of the foot and decreased loading underneath the lateral side in subjects with subsequent ERLLP: 1) first metatarsal contact was made with the fourth metatarsal head instead of

with the fifth, 2) the peak pressure and impulse underneath M_5 were significantly lower, 3) the medio-lateral ratio indicated that pressure distribution was more medially directed at forefoot flat and heel off and indicated a greater displacement of the pressure from lateral to medial in the forefoot contact phase, 4) the medio-lateral component of the COP was more medially positioned at forefoot flat and indicated less lateral displacement in the forefoot contact phase and 5) there was a higher eversion and abduction excursion in the rearfoot and accordingly increased eversion and abduction velocities in subjects susceptible to ERLLP.

Pronation is described as a triplanar motion consisting of the components eversion, abduction and dorsiflexion.²⁶ In a previous investigation, Engsborg indicated that in subjects with overpronation, dorsiflexion excursion during running was not increased, but eversion and abduction excursions were.²⁷ In our investigation, similar findings were observed since the dorsiflexion excursion was not significantly different between the groups, but eversion and abduction excursions were significantly increased in our injury group.

The results of this study confirm that overpronation and increased velocity of pronation was associated with an increased incidence of ERLLP as suggested before by many investigators.^{6,9,22,25,28-30} However, this is the first study to demonstrate this prospectively. During running, pronation is necessary to dissipate stress. When the rearfoot everts, the foot becomes a more mobile adaptor that allows shock attenuation.³¹ Because the rearfoot and the knee are mechanically linked by the tibia and because of the inclined axis of the subtalar joint in the sagittal plane, eversion in the foot normally leads to internal rotation at the knee.^{32,33} However, in our study eversion and abduction at the rearfoot was increased in the injury group but the internal rotation at the knee was not increased. These motions could be absorbed by musculoskeletal structures in the lower leg itself. However, it is difficult to confirm this because of the high inter-subject variability in eversion-internal rotation ratio³³ and because of the use of external markers, which are not as accurate as bone pins. McKeag and Dolan²⁸ found that in runners who overpronated, the transmission of force up the leg was exaggerated resulting in excessive midtibial torsion stress following exaggerated internal rotation during the stance phase, which supports the 'bone stress theory'. On the other hand, excessive eversion may be associated with increased internal inversion moments as the invertor musculature attempts to control the motion. This may lead to excessive eccentric traction to the plantar flexor and invertor musculature which

has their origin on the medial and posterior region of the tibia, and could be linked with the 'traction theory'. During running, each foot strikes the ground approximately 600 times per kilometer.³⁴ When each heel strike then generates a strain on the midtibial musculoskeletal structures, the musculoskeletal system may become overloaded and overuse injury may occur.

The second identified characteristic of the gait in subjects susceptible to ERLLP was hitting the ground with the centre of the heel instead of with the posterior and lateral border of the heel in controls. This is indicated by the anterior-posterior component of the COP which was positioned further forward in the injury group compared to the control group. In addition, in the injury group, the medial and lateral heel areas made contact at the same time. In the control group contact was made first with the lateral heel area and then with the medial heel area, which indicated an early pronation. During this initial pronation, first shock absorption may take place. We suggest that in our subjects who developed ERLLP subsequently, this early pronation did not take place because of the central heel strike. Therefore, shock absorption had to occur in the following pronation phase which will be exaggerated.

The third characteristic identified in subjects with subsequent ERLLP was an accelerated re-inversion with a more lateral roll-off. The more laterally situated position of the medio-lateral component of the COP at last foot contact and the more lateral displacements in the forefoot push off phase also accorded with these findings and the end of contact of M₂ and M₃ was delayed. Thus, the final roll off did not happen dominantly across the hallux as normal³⁵, but more laterally. This was probably caused by the diminished support at the first metatarsophalangeal joint, which showed a very mobile extension range of motion compared to the control group. During the re-inversion phase, bones of the midfoot become 'locked up', hence allowing the foot to become more stable to act as a rigid lever for push-off.³¹ During the pronation phase an excessive eversion took place, which led to a less stable foot. To compensate for this excessive eversion, a greater and accelerated re-inversion could occur to provide the rigid lever for push-off.

It is possible that static lower leg alignment characteristics may directly influence ERLLP by altering the forces applied to the lower leg. In the literature, numerous variables have

been assessed including range of rearfoot inversion-eversion, ankle dorsiflexion-plantar flexion and big toe flexion-extension. In the current study, we could not find a significant relationship between talocrural ranges of motion and ERLLP. Accordingly, most other investigations also failed to find a relationship^{29,36,37}, however in the study of Fredericson limited dorsiflexion had been associated with tibial stress fracture and MTSS.³⁸ In our study, all subjects had a normal dorsiflexion range of motion with a smallest range of 17 degrees. Even this range falls within the normal ankle dorsiflexion range and this ankle was flexible enough to perform a normal running pattern in which 15 degrees of dorsiflexion is regularly needed as seen in our population.

In contrast to the results of Viitasalo and Kvist⁷, our results identified no association of subtalar range of motion or the position of the calcaneus with ERLLP. Viitasalo and Kvist reported greater subtalar eversion and inversion range of motion in their subjects with MTSS compared with controls. Subtalar ranges of motion in our subjects were in accordance with those reported by Viitasalo and Kvist⁷ in their MTSS group. These values have been reported as normal in another study.³⁹ We therefore suggest that controls in the study of Viitasalo and Kvist⁷ had probably a limited range of subtalar motion.

In the investigation of Engsborg²⁷ no relationship could be found between static ranges of motion in the ankle and the dynamic kinematic data obtained during running. During running several movement excursions were significantly greater than the static ranges of motion. Greater ranges of motion were probably produced by the externally applied torques that occurred during running.²⁷ In addition, static measures lack the component 'velocity of motion', which can be an indicator for strain rate and linked with injury. Thus, we emphasize the need for dynamic measurements in aetiological investigations for activity related injuries.

Physical activity is mostly performed in shod conditions. However, the gait pattern in this study was measured during barefoot running which was for two reasons. Firstly, the purpose of this study was to determine gait related risk factors for ERLLP as *intrinsic* risk factors for this injury. Shod conditions could have masked the intrinsic biomechanics at the foot. Secondly, running and jogging are not the only risk-bearing sports activities for ERLLP. Other types of sports in which ERLLP is frequently encountered, are performed barefoot, for example dancing and gymnastics. Therefore, in a broad population, such as physical education students, testing barefoot can be considered as a functional measurement.

A limitation in this investigation was the large amount of variables in our statistical analysis. This increased the risk for significances (type I error) and decreased the power. As we analysed our data in a large cohort and not at the individual level, we are aware that not every identified intrinsic risk factor was present in every subject who developed ERLLP. Some subjects who had an increased risk because of the presence of an intrinsic risk factor did not develop ERLLP either.

CONCLUSION

This is the first prospective study that identified a central heel strike, an excessive eversion and an increased lateral roll-off as risk factors for ERLLP. Prevention programmes should examine these parameters and adapt them to reduce the incidence of ERLLP. In addition, treatment of ERLLP should consider altering these parameters. In the literature, it has been suggested that orthotic inserts, taping and antipronation shoes can limit pronation,^{4,40,41} which may reduce the incidence, prevent exacerbation and assist in the recovery from ERLLP.

Acknowledgements

This research was supported by BOF-RUG 01109001. The authors acknowledge Dr. Jan Verstuyft for data collection of injury occurrence, Ing. Pierre Van Cleven for technical support in data collection of plantar pressure and kinematics and Friso Hagman for model building.

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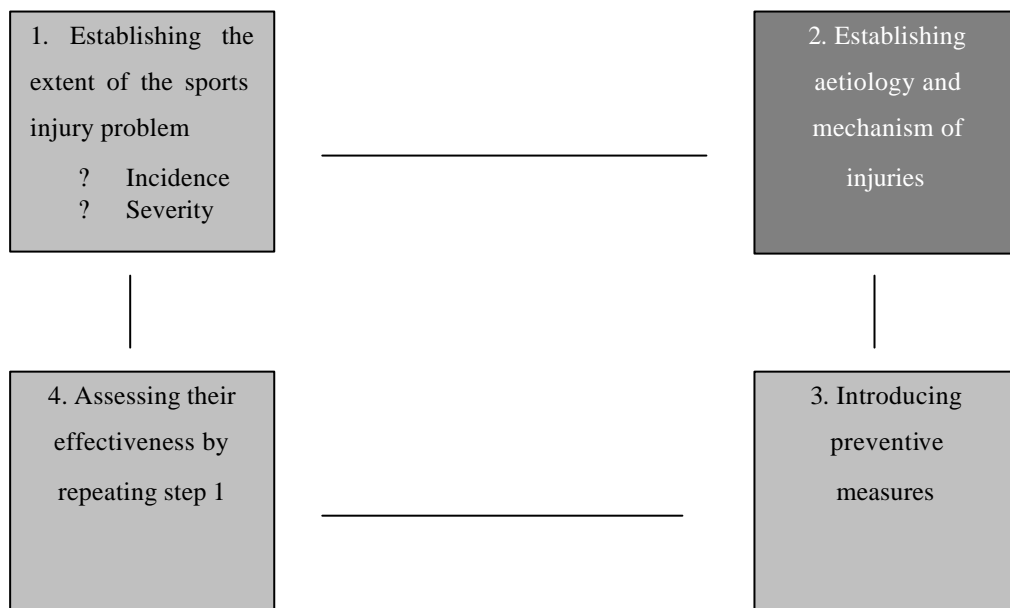
CHAPTER 7

GENERAL DISCUSSION

GENERAL DISCUSSION

The aim of this doctoral dissertation was to obtain a better insight in the intrinsic risk factors for sports injuries of the lower leg and ankle. However, this aim does not exist in isolation but constitutes a part of a bigger entity. Van Mechelen et al.⁶⁸ described this entity as a ‘sequence of prevention’ (Figure 1). He suggested a strategy of four stages in the sequence for the investigation of sports injuries.⁶⁸

Figure 1. The ‘sequence of prevention’ of sports injuries⁶⁸



First, the magnitude of the problem must be identified and described in terms of incidence and severity of sports injuries. Second, the risk factors and injury mechanisms that play a part in the occurrence of sports injuries must be identified. The third step is to introduce measures that are likely to reduce the future risk and/or severity of sports injuries. Such measures should be based on the information about the aetiological factors and the injury mechanisms as identified in the second step. Finally, the effect of the measures must be evaluated by repeating the first step.^{4,68}

In this doctoral dissertation, we emphasized on the second step of this sequence of prevention. Much has been written about the incidence and severity of injury of the lower

leg and ankle and many investigations established the extent of these injuries (first step).^{5,15,19,25,30-32,71,82}

Since the early 1980's, various authors have described the striking lack of risk factor studies.^{37,45,74} To date, however, few such studies have been reported in the international literature.¹² Only insight in the aetiology of sports injuries makes it possible to scientifically formulate preventive strategies. In future directions, the aim is preventing injuries from occurring in the first instance.

Although that the aetiology of sports injuries is still obscure, there have been several studies assessing the effectiveness of preventive strategies (step 3 and 4). These preventive measures were primarily a matter of trial and error. The interventions that have been examined in the literature range from stretching; warm-up and cool-down exercises; the use of ankle supports, taping, shoes and orthosis; proprioceptive and postural control training; strengthening exercises; technique training; physical conditioning; to multifaceted prevention programs. A lot of the introduced preventive strategies could not reduce the incidence of injuries.^{2,7,58,69} Some preventive strategies could reduce the overall incidence of injuries;⁷⁶ however, the benefit was mostly observed in athletes with a prior history of that injury.^{6,20,62,65,72}

However, from the perspective of the sequence, we suggest that future prevention programs should be based on identified risk factors from well-designed epidemiological studies and should be performed by the most suitable 'randomized controlled trials' study design.^{56,71}

Establishing injury mechanisms and aetiology of injuries

1. Sports injuries in general

The mechanisms responsible for injury are many and varied. Injury can result when a single overload exceeds a tissue's maximum tolerance. These injuries are called traumatic injuries. Long term repeated overload can result in overuse injuries. Traumatic and overuse injuries are usually distinguishable, but sometimes a relation exists between the two. For example, chronic loading (overuse) may weaken tissue, lower its maximum strength, and increase the likelihood of a traumatic injury.⁷⁷

The mechanical response of biological tissue depends largely on its noncellular structural make-up, including its constituent material, orientation, density, and connecting

substances. When different tissues form a functional unit, the weakest-link phenomenon typically occurs during an injury. This means that when a combined structure is mechanically loaded, it will likely fail first at the weakest link in the structural chain.⁷⁷

Simply stated, injury happens when an imposed load exceeds the tolerance (load-carrying ability) of a tissue. However, many contributing factors make this anything but a simple relation between load and injury. These factors have been traditionally divided into extrinsic and intrinsic risk factors^{42,43,63,68,81} and their contribution has been described in the multifactorial model of Meeuwisse⁴⁶ (cfr. General Introduction).

The aim of this dissertation was to gain a better insight into the aetiology of sports injuries of the lower leg and ankle with emphasis on the intrinsic risk factors.

After a preliminary retrospective study, a well-conducted prospective study was set-up to obtain a better understanding of the causation of sports injuries of the lower leg and ankle. Therefore, 400 physical education students were examined on potential intrinsic risk factors at the beginning of their academic study. The students were followed during the study by a sports physician in order to collect injury data. Freshmen in Physical Education in 2000-2001 (n=121) were followed during three years, freshman in 2001-2002 (n=133), during two years and freshman in 2002-2003 (n=146), during one year. However, due to quitting the education or not passing, only 55 subjects were followed for three years, 83 for two years and 215 for one year.

An additional goal of this investigation was to get an idea of the incidence of injuries in our physically active population. The total number of injuries of the lower leg, ankle and foot in these subjects was 241, of which 145 (60%) were traumatic injuries and 96 (40%) were overuse injuries. Consequently, the mean number of injuries per person is 0.68. During the total follow-up period, the traumatic injuries included: 93 ankle inversion sprains, six ankle eversion sprains, nine fractures (seven of phalanges, two of metatarsals), four strains, 32 sprains other than the ankle joint (mostly toe joints) and one distortion of the hallux. Ten subjects developed stress fractures (one sesamoid bone, one navicular bone, one first metatarsal, two fibulas, five tibias), 49 tibial stress syndrome, thirteen tendinopathy (eight of the Achilles tendon, three of the tibial posterior muscle and two of the tibial anterior muscle) and three subjects developed compartment syndrome. Nine subjects developed overuse strains, and twelve developed overuse injuries other than tibial stress syndrome or tendinopathy. As the two most common injuries were inversion ankle

sprains and exercise-related lower leg pain (tibial stress syndrome and stress fractures of the lower leg), we focused in this dissertation on the intrinsic risk factors for these two injuries.

2. *Inversion ankle sprains*

The first goal in this doctoral dissertation was to obtain a greater insight into the intrinsic risk factors for inversion ankle sprains.

Ankle sprains are the most common injuries sustained during sport.²⁵ This is probably the result of its relative anatomical instability and its supportive function. The determining factors in an ankle injury, as in most injuries, are the joint position at the time of injury, the magnitude, direction, and rate of the applied forces, and the resistance provided by surrounding structures. The mechanism of ankle sprains is inversion; this is a combination of ankle plantar flexion, subtalar varus and internal rotation of the foot in which the longitudinal midline of the foot deviates, or rotates, medially.

The static and dynamic stabilizers around the ankle joint contribute to the stability of the ankle: the ankle joint capsule and ligaments, and the muscles and tendons surrounding the ankle. In these structures as well as in the skin, several receptors (Ruffini receptors, Pacinian corpuscles, Golgi tendon organlike endings, free nerve endings, muscle spindles) receive sensory information. Their afferent inputs are integrated at all levels of the central nervous system to generate appropriate motor responses. The motor responses generally fall under three levels of motor control: the spinal cord for simple reflexes, the lower regions of the brain for more complicated responses, and the central cortex for control of the most complicated responses. Every deficit in a single structure or pathway in this sensorimotor system may increase the likelihood of an ankle injury. This can include deficits in proprioception, the mechanism and process occurring along the afferent (sensory) pathway, as well as in neuromuscular control, the unconscious efferent response to an afferent signal.⁴⁰ Ankle sprains are always high-speed events; so a quick and valid muscle response is necessary to avoid lesions. Deficits in strength of the structures around the ankle joint may contribute to ankle injury.

Although that ankle sprains are frequently encountered in the sports injury clinic, the different factors that increase the likelihood of these injuries remain enigmatic.¹⁰ Therefore, we conducted several studies to investigate the intrinsic risk factors for ankle sprains. In our first study (*chapter 2*), we investigated if ankle sprains are associated with

deficits in ankle muscle strength or joint position sense. Hereby, we investigated ankle muscle strength and joint position sense in subjects with a history of ankle sprains. Three groups of subjects were compared with a control group: subjects with subjective chronic ankle instability, subjects who had sustained an ankle sprain in the last two years without instability and subjects who sustained an ankle sprain three to five years earlier without instability. The results of this retrospective study showed that subjects with ankle instability had less accurate active joint position sense and lower relative eversion muscle strength compared with the symptom free control group. No significant differences were observed between the control group and the groups with past sprains without instability. However, because of the retrospective design of this study, we could not conclude that diminished active joint position sense and evetor muscle weakness are risk factors for ankle instability, nor could we exclude that they are no risk factors for ankle sprains. Although, as we found significant differences in subjects with ankle instability, we conclude that evetor muscle weakness and diminished active joint position sense are associated with ankle instability. Therefore, we recommend that the goal of rehabilitation programs for subjective ankle instability should be to increase proprioception and ankle evetor muscle strength. An alternative may be taping or bracing the unstable ankle, as this may improve proprioception on a short base.^{21,28}

Because of the retrospective design of the study, we were not able to identify diminished active joint position sense and evetor muscle weakness as risk factors for ankle sprains. It has been suggested in the literature, that a prospective cohort study is the appropriate model to study risk factors.³ Therefore, we decided to conduct a prospective study in which several possible risk factors were measured before the injury occurred.

In *chapter 3 and 4* a comprehensive, prospective investigation was performed on risk factors for inversion sprains in young physical active males and females. Two hundred and forty-one male and 159 female physical education students were evaluated for possible intrinsic risk factors for inversion sprains at the beginning of their academic study. In both investigations, the evaluated intrinsic risk factors included: anthropometrical and physical characteristics, ankle joint position sense, ankle muscle strength, lower leg alignment characteristics, postural control, and muscle reaction time during a sudden inversion perturbation. These variables were chosen since anthropometrical and physical characteristics,^{49,75} diminished proprioception,^{35,38} diminished muscle strength,^{27,51}

malalignment,^{59,80} diminished postural control,^{24,39} and delayed muscle reaction,^{13,34} have been associated with ankle sprains. By measuring all these variables, afferent and efferent signals were evaluated. Motor responses were evaluated on the three levels of motor control (spinal reflexes, brain stem activity, and cognitive programming). In addition, static as well as dynamic stabilizers of the ankle joint were investigated. After the evaluation, subjects were followed prospectively for one to three years.

It has been suggested to evaluate risk factors for men and women separately if the risk factors are gender dependent.^{10,11} Since there is a general agreement that anthropometrical and physical characteristics are different between males and females, separate analyses of the risk factors were performed for each sex (*chapter 3 and 4*).

Results of these investigations show that ankle injury rates are similar in male (18%) and female students (20%). Most of the ankle sprains affected the dominant ankle (59% in males, 80% in females). The ankle sprain incidence per 1000 hours of sports exposure was 0.75 in females and 0.64 in males. The results of our studies demonstrated that the risk factors that predispose an athlete to ankle ligament injury are different between men and women.

The investigation in male athletes showed that slower running speed and less cardiorespiratory endurance significantly increased the risk for ankle sprains in males. Our results confirm earlier statements that poor physical condition enhances the risk of a sports injury in males. Diminished physical fitness could cause earlier fatigue leading to a less accurate protective effect of the musculature on capsuloligamentous structures. Our results also identify that males with less general balance, less movement coordination, and decreased reaction time of the tibialis anterior and the gastrocnemius muscles have a significantly increased risk of an ankle sprain. Balance, coordination and muscle reaction are three systems that utilize complex processes involving both sensory and motor components. As these variables constitute a part of the sensorimotor system, we can conclude that deficits in this system contribute to the development of ankle sprains. We also identified decreased dorsiflexion range of motion and decreased dorsiflexion muscle strength as risk factors for ankle sprains in male athletes. As our results show that decreased dorsiflexion muscle strength is a risk factor for ankle sprains, we suggest that subjects susceptible to ankle sprains could not accurately perform a strong dorsiflexion in their ankle when an inversion action occurred. On the other hand, their ankles might have

been placed in a more plantar flexed position in different sports tasks and increased the risk for sprains.

For female athletes, less coordination and less accurate passive joint position sense were determined as risk factors for ankle sprains. As in males, deficits in the sensorimotor system increased the risk for ankle sprains in females, as joint position sense and coordination both are a part of this system. A higher extension range of motion at the first metatarsophalangeal joint also increased the risk for ankle sprains in females. The higher extension range of motion at the first metatarsophalangeal joint probably caused a diminished support at this joint during gait. Making the link with the biomechanics in the unrolling foot (*chapter 5*), we suggest that through this altered mechanism, foot roll-off does not primarily occur across the hallux as normal, but more laterally in subjects susceptible to ankle sprains. Because of this diminished support, we suggest that, when landing from a jump, contact is also made with the lateral part of the foot instead of with the hallux. This position is very susceptible for inversion sprains and could explain the higher incidence of ankle sprains in subjects with a higher extension range of motion at the first metatarsophalangeal joint.

Based on the results of these three investigations, we derive that evtor muscle weakness and diminished active joint position sense, detected in our retrospective investigation, are presumably no risk factors for ankle sprains, as we could not detect these deficits in subjects susceptible to ankle sprains in our prospective investigations. However, these deficits are associated with ankle instability as these alterations are demonstrated in subjects with recurrent ankle sprains, but not in subjects with ankle sprains in the past without instability complaints.

It has been assumed that biomechanical abnormalities in gait play an important role in the aetiology of inversion sprains and that accurate positioning of the foot at touchdown is very important in gait and sport. However, despite the believe that these factors play a role in the development of ankle sprains, no prospective studies have been undertaken to determine the role of dynamic gait related risk factors. Contrary to anthropometrical and physical characteristics, the influence of gender is negligible in the foot unroll during running.¹⁸ Therefore, in the investigation to gait related risk factors of ankle sprains (*chapter 5*), we used the approach of analysing both sexes as a group.

In our fourth study (*chapter 5*), we focused our prospective investigation on the gait related risk factors for ankle sprains by evaluating alignment characteristics and measuring plantar pressure and 3D-kinematics during running. The most striking results of this study is that the gait of subjects who are at increased risk of sustaining an inversion sprain show a trend towards a laterally situated centre of pressure (COP) at initial contact. This implies that the trust needed to invert the ankle is smaller in these subjects, which predisposes them to inversion sprains. In addition, the gait of subjects susceptible to ankle sprains also showed a significantly more medially directed pressure distribution at first metatarsal contact, forefoot flat and heel off. Biomechanically, there is no direct relation between inversion sprains and an increase in medial loading. However, we suggest that subjects susceptible to inversion sprains may have an unstable feeling and try to unroll their feet more medially as a compensation to avoid lateral inversion sprains. Finally, in our subjects susceptible to ankle sprains resupination was significantly delayed and increased. The roll off did not occur across the hallux, but more laterally, probably because of the diminished support at the first metatarsophalangeal joint. We suggest that when these subjects land from a jump, first contact is also made more laterally, as the same roll off pattern occurs in the opposite direction as in running.⁶⁶ This plantar flexed position with the inversion component is very susceptible for inversion sprains and probably predisposes subjects with a lateral roll off to inversion sprains.

To assess the influence of all measured variables on the hazard of injury and to know which variables strongly predict the subsequent outcome (injury or not), a multivariate forward stepwise Wald Cox regression analysis was performed taking into account all the variables that showed significant association in the univariate Cox regression analysis (*Appendix 1*).

The most contributing variable ($P = .025$) for ankle sprains in men was the dorsiflexion strength at 30°/s compared to body weight ($P = .030$). This means that subjects with decreased dorsiflexion muscle strength were at increased risk for having an ankle sprain and those with increased dorsiflexion muscle strength were protected against it. Every decrease of the strength value with 0.1 Nm/kg increased the hazard of an ankle sprain with 32% (95% CI: 2-70%). Consequently, subjects with a decrease of the mean strength with 0.3 Nm/kg, had approximately twice (increase of 96%) the risk of sustaining an ankle sprain.

For females, the most contributing variables ($P = .002$) were passive joint position sense at 15° of inversion ($P = .025$), the position of the medio-lateral component of the COP at first foot contact ($P = .026$) and the position of this component at last foot contact ($P = .012$). Every increase of one degree of the absolute error on the passive joint position test increased the hazard of an ankle sprain with 10% (95% CI: 1-20%). The hazard increased with 36% (95% CI: 4-78%) with every decrease (more lateral position) of one value in the medio-lateral component of the COP scaled to the foot width at first foot contact, and with 10% (95% CI: 2-19%) with every decrease of the value of this component at last foot contact.

In conclusion, the most contributing intrinsic risk factor for ankle sprains in males was decreased dorsiflexion muscle strength. For females, the most contributing risk factors were decreased passive joint position sense and a more laterally situated COP at first foot contact and last foot contact.

3. *Exercise-related lower leg pain*

The second objective of this doctoral dissertation was to obtain a greater insight into the intrinsic risk factors for exercise-related lower leg pain.

Exercise-related lower leg pain is a common and enigmatic overuse problem in athletes.⁸ However, the exact pathophysiology of this syndrome remains controversial. Some authors postulate that it results from fatigue damage in bone (bone stress theory), while others postulate that it results from a traction periostitis relating to the origin of the tibialis posterior muscle or insertion of the crural fascia ('soleus bridge') along the postero-medial tibia (traction theory).^{26,33,48,50}

The causes of exercise-related lower leg pain are not always easily determined but are often linked to repetitive stress.³⁶ In the literature, exercise-related lower leg pain is often attributed to deviations in alignment characteristics and gait patterns. Clinical observations have noted an increased foot pronation and static pronated feet in subjects with exercise-related lower leg pain.^{47,61,73} However, no prospective research has been conducted on these potential risk factors and the causes of exercise-related lower leg pain remain enigmatic.⁵³ Therefore, in *chapter 6*, we focused our investigation on gait related risk factors for exercise-related lower leg pain. The examined factors included static lower leg alignment, 3D kinematics of the foot-shank-thigh complex and plantar pressure measurements during running. Since the influence of gender is negligible in the foot unroll

during running,¹⁸ data from both sexes were analysed as a group. During the follow-up period, 11.5% of the 400 subjects developed exercise-related lower leg pain. Sixty-three percent of these subjects had symptoms in both legs. We found an increased risk for exercise-related lower leg pain in women, as 18% of the female subjects developed exercise-related lower leg pain versus 7% of the male subjects. The exercise-related lower leg pain incidence per 1000 hours of sports exposure was 0.76 in females and 0.25 in males. Results of our investigation reveal that subjects susceptible to exercise-related lower leg pain have an altered running pattern compared to the control subjects.

The most striking result of this investigation is that an increased eversion with an increased loading underneath the medial side of the foot increases the risk for exercise-related lower leg pain. This finding can be functionally linked with both pathophysiological theories. As we see in our study that eversion at the rearfoot is increased in our injury group but the internal rotation at the knee is not increased although that they are mechanically linked by the tibia, these motions were probably absorbed by musculoskeletal structures in the lower leg itself. McKeag and Dolan⁴⁴ found that in runners who overpronate, the transmission of force up the leg is exaggerated resulting in excessive midtibial torsion stress following exaggerated internal rotation during the stance phase. This explanation supports the 'bone stress theory'. On the other hand, excessive eversion may be associated with increased inversion moments as the invertor musculature attempts to control the motion. This may lead to excessive eccentric traction to the invertor and plantar flexor musculature which has their origin on the medial and posterior region of the tibia, and could be linked with the 'traction theory'. The risk of exercise-related lower leg pain increased when the position of the COP is situated further forward at first foot contact. This refers to a central heel strike instead of making contact with the lateral-posterior border of the heel seen in control subjects. We suggest that this indicated that the early pronation did not take place and that shock absorption had to occur in the following pronation phase which was exaggerated. The risk of exercise-related lower leg pain also increased with an accelerated re-inversion and increased lateral roll-off. In subjects susceptible to exercise-related lower leg pain, the roll off did not happen across the hallux as normal, but more laterally, probably because of the diminished support at the first metatarsophalangeal joint. During the pronation phase, an excessive eversion took place, which led to a less stable foot. To compensate for this excessive eversion, an accelerated re-inversion with an increased lateral roll-off could have occurred to provide the rigid lever for push-off.

The aetiology of exercise-related lower leg pain is multifactorial, in which intrinsic and extrinsic risk factors play their part. Besides the contribution of adverse biomechanics in the development of exercise-related lower leg pain, extremes in height and body fat, body build, poor physical condition, decreased muscle strength and muscle fatigue, and poor coordination have been quoted as intrinsic risk factors.^{8,9,64} In order to obtain a greater insight into the intrinsic risk factors of this injury, beside the gait related risk factors, other potential risk factors were registered. These included anthropometrical and physical characteristics, ankle plantar-dorsiflexion and inversion-eversion muscle strength, joint position sense, postural control, muscle reaction time, and bone mineral density. Analysis of these variables showed no association with the development of exercise-related lower leg pain. Therefore, we can conclude that adverse biomechanics are the most contributing intrinsic risk factors in the development of exercise-related lower leg pain. Results of the multivariate stepwise Cox regression analysis ($P < .001$) indicate that the anterior-posterior component of the COP at first foot contact ($P = .087$), the medio-lateral ratio during the forefoot contact phase ($P = .007$) and the medio-lateral component of the COP at last foot contact ($P < .001$) are the best predictors of exercise-related lower leg pain (*Appendix 2*). The more forward the position of the anterior-posterior component of the COP at first foot contact, the higher the risk of exercise-related lower leg pain (increase of the hazard with 8% (95% CI: 0-19%) every increase in one value of the COP). The hazard of exercise-related lower leg pain increased with 43% (95% CI: 3-669%) when the medio-lateral ratio during forefoot contact phase increased with one value (more pressure medial) and with 14% (95% CI: 6-23%) when the medio-lateral component of the COP at last foot contact decreased with one value (more lateral position).

In conclusion, risk of exercise-related lower leg pain increased the more forward the COP is situated at first foot contact, the more medial the pressure is distributed during the forefoot contact phase and the more lateral the COP is situated at last foot contact.

Introducing preventive measures

Clearly, prevention or early intervention of an injury is preferable to treating an injury.^{19,23,78} Prevention screening should take place to assess risk factors that could lead to sports injuries. Strategies for intervention have been termed 'primary prevention'.²² Assessment of many of the extrinsic risk factors becomes the responsibility of the coach or

trainer or athlete who directly determines equipment, footwear, playing surface and training schedules. Intrinsic risk factors require clinical assessment for their identification.¹⁶ Identification and modification of these risk factors can be attributed to the role of the physical therapist.

Beside the screening on potential risk factors and introducing preventive measures, health education principles should also be applied.⁷⁰ The athletes should be educated by telling them why and how to implement the proposed preventive measures.

Based on the information about the aetiological factors provided by establishing the intrinsic risk factors of sports injuries in our investigations (step 2 in van Mechelen's model⁶⁸), we can propose preventive strategies to introduce measures that are likely to reduce the future risk and/or severity of sports injuries (step 3).

Based on our findings in the first part of this dissertation, we recommend that in order to decrease the incidence of ankle sprains all male athletes should be screened on cardiorespiratory endurance, running speed, dorsiflexion range of motion, balance, coordination, the recruitment pattern of the ankle muscles and especially dorsiflexion muscle strength. Females should be screened on coordination, extension range of motion of the first metatarsophalangeal joint and especially passive joint position sense and the running pattern. Athletes with an increased risk should be given a prevention program designed to adapt the intrinsic risk factor.

Several ways exist to work out preventive strategies. These include scientifically based techniques and/or exercises which can adapt the identified intrinsic risk factors. In the following part of this dissertation, we propose some of these techniques; however, this list is not limited and other techniques can be added.

To progressively increase cardiorespiratory endurance and speed training, many programs exist. Any activity that increases heart rate and breathing for an extended period of time can be performed to increase cardiorespiratory endurance. ACSM's latest recommendation for developing and maintaining cardiorespiratory fitness in healthy adults gives 55/65%-90% of maximum heart rate or 40/50%-85% of oxygen uptake reserve as the intensity limits.⁵⁷

When performing exercises to enhance one of the subserving systems of the sensorimotor system, all the others will be activated and trained as well. Therefore, balance, coordination, proprioception and muscle reaction will improve during any kind of neuromuscular control training. On the other hand, each of the three levels of motor control (the spinal reflex, the brain stem and cognitive programming) should be specifically addressed during exercises.

At the spinal level, activities that induce reflex joint stabilization should be trained. These activities should include sudden alterations in joint positioning that require reflex muscular stabilization. In order to induce the alterations in joint position, unstable surfaces can be used. During these exercises, the ankle should be placed in vulnerable positions. Attention should also be paid on the recruitment pattern of the ankle musculature. When inversion perturbations are performed, the evertor musculature should react first, before the gastrocnemius and tibialis anterior muscles. To visualize the reaction of the muscles, feedback may be performed by surface-electromyography.

To enhance the second level of motor control (the brain stem level), exercises to maintain balance and posture of the body should be performed. Increasing the difficulty of these exercises can be done by decreasing the stability of the surface. A common progression when performing balance exercises is to move from bilateral to unilateral stance, eyes open to eyes closed, firm surface to soft, uneven or moving surface.

Cognitive appreciation of joint position should also be addressed. These activities are initiated at the cognitive level and include programming motor commands for voluntary movement. The repetition of movements will initiate the conversion of conscious programming to unconscious programming. Joint position sensibility exercises focus on restoring joint position sense. This can be accomplished through joint repositioning types of exercises. These exercises may be performed on an isokinetic dynamometer or with devices such as a goniometer. These types of joint repositioning exercises should emphasize functional positioning and especially plantar flexed and inversion positions.

During coordination exercises smooth, accurate and controlled movement tasks should be performed. Coordinated movements involve proper sequencing and timing of synergistic and reciprocal muscle activity. Coordination is trained by asking skills as moving the center of gravity between the limits of stability. These exercises can be easily performed on a monitored force platform.

Neuromuscular exercises must be performed throughout the total range of motion. This is important because the mechanoreceptors seem to be activated selectively at specific angles. Muscle receptors play a primary role in the intermediate range of motion, while joint receptors together with muscle receptors are more important in the extreme ranges of motion. For the athletes, functional exercises should be sports-specific.

Dorsiflexion muscle strengthening exercises should also be included in the prevention program for males. Exercise materials that can be used are isokinetic devices, manual resistance, exercise bands, ankle weights, hand-held dynamometers, etc.

To increase the dorsiflexion range of motion strategies as stretching can be included. As the dorsiflexion range of motion with the knee straight was determined as risk factor in males, stretching techniques should especially be performed for the gastrocnemius muscle.

In order to prevent ankle sprains, attention should also be paid to the gait pattern, especially in female athletes. Adjustments of altered foot biomechanics can include ankle taping, bracing or orthotics to resituate the COP at initial contact, limit the pronation and reduce the extension at the first metatarsophalangeal joint through which the resupination should occur across the hallux. Other modalities to adapt the gait pattern have not been described in the literature. However, in the future, strategies should be developed to alter individual's biomechanics through techniques such as biofeedback and gait retraining.

Taping and bracing could also counterbalance intrinsic risk factors for ankle sprains. Both are considered to have an influence on neuromuscular activity of the ankle joint and could therefore protect an ankle from sprains. They may increase the afferent feedback from mechanoreceptors, which reduces the error in joint position sense.^{21,28} By using these devices, inversion range of motion is reduced for a certain period, and above all, there is a reduction in angular velocity. This lower speed of inversion allows active stabilizers to react with a more valid response.⁴¹

The findings of the second part of this dissertation suggest that altered biomechanics play a major role in the genesis of exercise-related lower leg pain. In order to decrease the incidence of exercise-related lower leg pain, athletes should be screened on the foot-unroll

during running. Special attention should be paid on the position of the COP at heel strike, the pressure distribution during the forefoot contact phase and the position of the COP at last foot contact. In subjects susceptible to exercise-related lower leg pain, we suggest that the primary objective is to minimize the eversion excursion as an increased eversion and medial pressure distribution can be linked with the pathophysiological development of the injury. These strategies could consist of tape, inserts or orthotics in the shoe or specially designed adequate antipronation shoes. Numerous investigations have been performed on the efficacy of foot orthoses and evidence exists, based on subjective pain relief and symptom resolution; however, scientific evidence is equivocal^{29,52} These strategies may similarly decrease the increased re-inversion velocity and the increased lateral roll off and provide the foot making contact with the lateral-posterior border of the heel instead of with the centre of the heel. In the future, techniques such as biofeedback and gait retraining may be valuable. However, no scientific evidence exists if these strategies are effective.

In the literature, very few studies are available on effective injury prevention given the limited information available on risk factors and injury mechanisms.^{4,56} Whether the recommendations we just made in this dissertation really will prevent, and thus reduce the amount of injuries, remains unknown. Future research should focus on assessing their effectiveness by repeating step 1.

There is saying in sport that “injury is just part of the game”. In other words, injury is seen as an inevitable consequence of participation in sports.¹⁴ As sports injury prevention researchers and practitioners, we hold a contrary view. We argue that sports injuries should be prevented and need not be a part of the game. Now that intrinsic risk factors are determined, research on how to prevent sports injuries is urgently required.

Strengths and limitations of the study and future directions.

This is one of very few prospective studies on the aetiology of sports injuries of the lower leg and ankle. The very high recruitment and retention rate is a study strength, as are the use of clinically relevant performed measures. The cooperation with a high educated physician in sports medicine, who diagnosed the sports injuries, is also a strength of this study. The adequate definition of a sports injury, the calculation of extramural activities

and the proper statistical analysis, add to the value of the study. However, limitations of this study include several issues. A limitation that will always be present in injury epidemiological research is the fact that not all contributing factors can be measured. However, in this investigation various potential risk factors have been established. The selection of the investigated potential risk factors was based on a thorough study of the available literature on prospective and retrospective studies which showed an association between the variables and the injury. The methods used to measure these variables were selected according to the reliability of the procedures and the availability of the equipment. Almost all the investigated variables showed good to excellent reliability (*Appendix 3*).^{17,18,54,55,60,67,79} A limitation in this investigation was, however, the large amount of independent variables included in the statistical analysis. This led to an increased possibility of a type I error. However, a Bonferroni correction was not applicable as all the variables that were evaluated in this study were strongly correlated. Therefore, unadjusted *P*-values were reported, according to the recommendations of Altman et al.¹ In this investigation, research was performed towards the intrinsic risk factors, because general agreement in the literature already exists on the extrinsic risk factors and little is known about intrinsic risk factors. However, future research should also take the type and intensity of physical activity into consideration, as these are very important extrinsic risk factors, which can have a substantial influence on the multifactorial aetiology of sports injuries.

In addition, most probably, other intrinsic risk factors can also play a role in the aetiology of injuries. One of these factors are psychosocial variables, which have not been analysed so far and limited scientific evidence exists. Therefore, future research should establish the influence of factors as psychosocial stress and personality-profile (e.g. self-concept, readiness to take risk, fear of fail, stress-coping strategy) on risk of injuries.

Our first intention was to obtain greater insight into intrinsic risk factors for other sports injuries than ankle sprains and exercise-related lower leg pain as well. However, incidence of these injuries was too low to perform adequate statistical analysis. Therefore, this dissertation was limited to reporting incidences of sports injuries to the lower leg ankle, and foot and no intrinsic risk factors were evaluated for those injuries other than ankle sprains and exercise-related lower leg pain.

A limitation in this study is our narrow view on the steadiness of the intrinsic risk factors. During this investigation we have neglected that intrinsic risk factors can change over time. The intrinsic risk factors have been measured once at the beginning of their education. However, during the following years of education, some of these variables will probably be modified by the amount of physical activity students participate in. Future research should bring clarity in the steadiness of intrinsic risk factors.

Another limitation is that most of the evaluation methods for the intrinsic risk factors can not be performed at the field. Most of them can only be assessed in the laboratory. The equipment is expensive and is therefore not affordable for any practitioner. In addition, evaluating intrinsic risk factors involves a lot of manpower and time. However, considering morbidity, medical costs and the persistent disability that often arises from an injury, screening on intrinsic risk factors and introducing preventive strategies seems required. Future research could concentrate on the development of validated methods to assess intrinsic risk factors that can be more easily performed at the field.

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CHAPTER 8

NEDERLANDSTALIGE SAMENVATTING

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Letsels t.h.v. onderbeen en enkel komen zeer frequent voor tijdens sportbeoefening. Enkeldistorsies zijn de meest voorkomende traumatische letsels bij sportbeoefenaars. Daarnaast is bewegingsgerelateerde onderbeenpijn, zoals periostitis, stress fractures en compartimentsyndroom, een vaak voorkomend overbelastingsletsel. Ondanks hun hoge incidentie blijft inzicht in de etiopathogenese van deze aandoeningen onduidelijk. Op basis van epidemiologische studies kan gesteld worden dat het ontstaan van deze letsels een multifactorieel probleem is waarin zowel extrinsieke (omgevingsgebonden) als intrinsieke (persoonsgebonden) predisponerende factoren een belangrijke rol kunnen spelen. Tot op heden zijn echter weinig onderzoeksresultaten voorhanden waarin de invloed van intrinsieke risicofactoren in het ontstaan van deze letsels op een prospectieve wijze werden onderzocht. Onvoldoende kennis over de predisponerende factoren van deze aandoeningen maken het onmogelijk om een wetenschappelijk gefundeerd preventief of therapeutisch programma samen te stellen. Slechts na identificatie van deze risicofactoren wordt een degelijke en wetenschappelijk onderbouwde remediëring van deze letsels mogelijk.

Met als doel de intrinsieke risicofactoren van locomotorische aandoeningen t.h.v. onderbeen en enkel te identificeren werden een aantal studies opgezet bij studenten Lichamelijke Opvoeding aan de Universiteit Gent. Deze populatie werd verkozen gezien de extrinsieke factoren, zoals sportprogramma, speeltechniek, sportaccommodaties, enz. bij deze studenten enigszins onder controle gehouden kunnen worden.

Het eerste deel van dit proefschrift handelt over de intrinsieke risicofactoren van enkeldistorsies. In een eerste onderzoek werd retrospectief nagegaan of er deficiënties zijn in de kracht van de enkelmusculatuur en/of de proprioceptie bij personen met chronische enkelinstabiliteit en bij personen die een voorgeschiedenis van enkeldistorsies hebben zonder instabiliteit t.o.v. een controle groep. De resultaten van dit onderzoek toonden aan dat personen met chronische instabiliteit een gedaalde eversiekracht en een verminderde actieve repositiezin hadden t.o.v. de controlegroep. De personen die in het verleden een enkeldistorsie opliepen zonder symptomen van instabiliteit vertoonden geen significante verschillen in proprioceptie en kracht t.o.v. de controlegroep. In de twee daaropvolgende studies werd op een prospectieve manier nagegaan of er een verband bestaat tussen

enkeldistorsies en antropometrische karakteristieken, fysieke fitheid, alignement-karakteristieken, musculaire factoren zoals spierkracht en reflex-responstijd bij een onverwachte kantelbeweging, proprioceptie van het enkelgewricht en posturale controle. Bij de aanvang van het academiejaar 2000-2001, 2001-2002 en 2002-2003 werden de generatiestudenten geëvalueerd op deze potentiële intrinsieke risicofactoren. Vervolgens werden deze studenten gedurende drie jaar (generatiestudenten 2000-2001), twee jaar (generatiestudenten 2001-2002) en één jaar (generatiestudenten 2002-2003) gevolgd met betrekking tot het oplopen van enkeldistorsies. Vervolgens werd getracht om een relatie tussen de geselecteerde intrinsieke risicofactoren en het oplopen van enkeldistorsies aan te tonen zowel bij mannen als bij vrouwen. Uit deze onderzoeken bleek dat de letselincidentie voor mannen (18%) en vrouwen (20%) ongeveer gelijk was. Het merendeel van de enkeldistorsies werden vastgesteld aan de dominante zijde. Volgende parameters konden weerhouden worden als intrinsieke risicofactoren bij mannen: 1) een gedaalde cardio-respiratoire uithouding, 2) een tragere maximale loopsnelheid, 3) verminderd algemeen evenwicht, 4) gedaalde coördinatie, 5) verminderde dorsiflexie-beweeglijkheid in het enkelgewricht, 6) gedaalde dorsiflexiekracht en 7) een versnelde reactie van de m. tibialis anterior en m. gastrocnemius tijdens een onverwachte kanteling van de voet. Voor de vrouwelijke sporters werden 1) een verminderde coördinatie, 2) een grotere extensiemogelijkheid in het eerste metatarsophalangeaal gewricht en 3) een verminderde proprioceptie als risicofactoren op enkeldistorsies aangetoond.

In een volgend onderzoek werd prospectief nagegaan of parameters van het gangpatroon predisponerend zijn voor het oplopen van enkeldistorsies. Uit deze studie bleek dat het risico op enkeldistorsies vergroot wanneer het drukcentrum van de hiel bij initieel contact meer lateraalwaarts gelegen is, gedurende de midstance fase de drukverplaatsing naar mediaal vergroot is en bij de afstoot de resupinatie vertraagd en vergroot is.

In het tweede deel van dit proefschrift werd nagegaan of parameters van het gangpatroon predisponerend zijn voor het oplopen van bewegingsgerelateerde onderbeenpijn. Gedurende de follow-up periode van één tot drie jaar, ontwikkelden 11.5% van de studenten bewegingsgerelateerde onderbeenpijn. Drieënzestig procent van deze studenten had bilaterale klachten. Studenten met een afwijkend gangpatroon waren voorbeschikt om bewegingsgerelateerde onderbeenpijn te ontwikkelen. Als risicofactoren voor deze pathologie werden volgende parameters weerhouden: 1) een verder voorwaarts gelegen

drukcentrum bij initieel contact, 2) een verhoogde en versnelde eversie met een verhoogde mediale druk tijdens midstance en 3) een verhoogde en versnelde resupinatie.

Om de incidentie van enkeldistorsies en bewegingsgerelateerde onderbeenpijn te doen dalen, dienen atleten eerst gescreend te worden op de aanwezigheid van de risicofactoren. Preventieve maatregelen dienen dan deze risicofactoren aan te passen.

CHAPTER 9

APPENDICES

Appendix 1: Risk model for ankle sprains

Table 1. Risk model for males ($P = .025$) for the prediction of ankle sprains versus no injury obtained by multivariate Cox regression.

	B	SE	P-value	Exp(B)	95% CI for Exp(B)
DF 30°/s /BW	-.278	.128	.030	.758	.589 - .974

B=regression coefficient, SE=standard error, Exp(B)=hazard rate, CI=Confidence Interval

DF 30°/s /BW= concentric dorsiflexion muscle strength at 30°/s divided by bodyweight (x10)

Table 2. Risk model for females ($P = .002$) for the prediction of ankle sprains versus no injury obtained by multivariate Cox regression.

	B	SE	P-value	Exp(B)	95% CI for Exp(B)
X-comp FFC	-.306	.137	.026	.736	.562 - .964
X-comp LFC	-.098	.039	.012	.907	.840 - .979
Abs P 15° INV	.099	.044	.025	1.104	1.013 - 1.204

B=regression coefficient, SE=standard error, Exp(B)=hazard rate, CI=Confidence Interval

X-comp=medio-lateral component of the centre of pressure, FFC=first foot contact, LFC=last foot contact, Abs P 15° INV=absolute error in degrees for passive joint position sense at the test position of 15° inversion

Appendix 2: Risk model for exercise-related lower leg pain

Table. Risk model ($P < .001$) for the prediction of exercise-related lower leg pain versus no injury obtained by multivariate Cox regression.

	B	SE	P-value	Exp(B)	95% CI for Exp(B)
Y-comp FFC	.081	.047	.087	1.084	.988-1.189
Ratio FFCP	3.762	1.400	.007	43.047	2.769-669.275
X-comp LFC	-.134	.038	<.001	.874	.811-.942

B=regression coefficient, *SE*=standard error, *Exp(B)*=hazard rate, *CI*=Confidence Interval

Y-comp=anterior-posterior component of the centre of pressure, *FFC*= first foot contact, *Ratio*=[$(H_M+M_1+M_2)-(H_L+M_4+M_5)$] $\times 100$ /sum of the pressure underneath all areas, *FFCP*=forefoot contact phase, *X-comp*=medio-lateral component of the centre of pressure, *LFC*=last foot contact

Appendix 3: Reliability of measured variables

Table 1. Test-retest reliability of isokinetic muscle strength parameters, joint position sense, lower leg alignment characteristics, tested on 18 lower legs with an interval of one week.

Variables	Session 1	Session 2	ICC	P value
Eversion (Nm)				
30°/s concentric	19.39 ? 3.27	21.46 ? 3.83	.725	.013
30°/s eccentric	20.49 ? 4.48	23.14 ? 3.79	.782	.002
120°/s concentric	17.36 ? 5.24	20.22 ? 3.77	.853	<.001
120°/s eccentric	21.18 ? 5.91	23.54 ? 3.80	.803	.001
Inversion (Nm)				
30°/s concentric	31.24 ? 10.64	36.27 ? 15.79	.889	<.001
30°/s eccentric	31.13 ? 9.66	35.61 ? 13.45	.919	<.001
120°/s concentric	31.58 ? 10.73	34.31 ? 13.35	.910	<.001
120°/s eccentric	33.80 ? 11.45	37.32 ? 13.60	.910	<.001
Plantar flexion (Nm)				
30°/s concentric	114.82 ? 42.36	108.47 ? 25.60	.769	.067
120°/s concentric	64.77 ± 17.72	64.43 ? 12.84	.816	.043
Dorsiflexion (Nm)				
30°/s concentric	18.15 ? 3.13	18.78 ? 2.36	.884	.017
120°/s concentric	13.02 ? 3.92	12.12 ? 3.21	.888	.016
Exact passive joint-position sense				
10° of eversion	4.19 ± 3.77	2.19 ± 2.98	.695	.009
15° of inversion	3.64 ± 2.82	3.08 ± 3.44	.906	<.001
Maximal active inversion minus 5°	3.33 ± 3.61	2.33 ± 3.69	.894	<.001
Exact active joint-position sense				
10° of eversion	0.36 ± 2.96	-0.64 ± 2.97	.776	.002
15° of inversion	2.31 ± 4.67	0.92 ± 2.85	.629	.024
Maximal active inversion minus 5°	-0.19 ± 3.85	-0.25 ± 4.20	.676	.013
Absolute passive joint-position sense				
10° of eversion	5.19 ± 3.06	3.64 ± 2.45	.714	.007
15° of inversion	3.97 ± 2.51	3.81 ± 2.84	.895	<.001
Maximal active inversion minus 5°	4.22 ± 2.79	3.94 ± 2.26	.877	<.001
Absolute active joint-position sense				
10° of eversion	3.36 ± 1.55	2.66 ± 1.61	.093	.426
15° of inversion	5.03 ± 3.84	3.36 ± 2.27	.731	.005
Maximal active inversion minus 5°	3.47 ± 2.01	2.40 ± 0.93	.604	.047
Lower leg alignment characteristics				
Talocrural PF	59.90 ± 5.87	59.35 ± 4.32	.899	<.001
Talocrural DF (knee extended)	34.75 ± 6.31	33.90 ± 7.79	.921	<.001
Talocrural DF (knee flexed)	42.65 ± 6.24	42.45 ± 6.61	.861	<.001
Subtalar INV	22.60 ± 4.25	22.55 ± 5.74	.720	.004
Subtalar EV	5.95 ± 3.33	6.30 ± 4.29	.721	.004
MTPIJ flexion	43.90 ± 13.88	44.50 ± 13.60	.945	<.001
MTPIJ extension	78.50 ± 10.38	77.05 ± 9.97	.912	<.001
Hip external rotation	42.60 ± 6.23	44.00 ± 4.54	.899	<.001
Hip internal rotation	41.95 ± 3.87	42.40 ± 5.62	.799	.001
Position calc unloaded (STJN)	.50 var ± 1.87	2.00 valg ± 1.67	.822	.041
Position calc WB (STJN)	0.40 var ± 2.80	0.45 var ± 2.31	.866	<.001
Position calc WB	3.60 valg ± 2.54	3.50 valg ± 2.82	.904	<.001

Values are mean degrees ± SD, ICC=intraclass correlation coefficient

Table 2. *Intrasubject-reliability of the muscle reaction time between 5 trials of 30 subjects.*

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	ICC	P-value
Peroneus longus	77.87 ± 13.75	79.27 ± 15.73	82.90 ± 14.95	80.60 ± 16.91	80.03 ± 15.74	.746	<.001
Peroneus brevis	80.83 ± 17.45	81.23 ± 17.86	83.87 ± 14.50	79.47 ± 14.35	83.87 ± 13.21	.774	<.001
Tibialis anterior	91.60 ± 18.02	87.57 ± 15.29	85.30 ± 11.15	84.83 ± 16.88	89.70 ± 14.70	.731	<.001
Gastrocnemius	83.30 ± 21.89	84.63 ± 19.32	79.27 ± 17.41	85.47 ± 24.95	85.03 ± 20.75	.794	<.001

Values are mean degrees ± SD, ICC=intraclass correlation coefficient