Risk Factors for Lower Extremity Injuries in Recreational Runners

Dennis van Poppel

The work presented in this thesis was carried out within The Department of General Practice of the Erasmus Medical Center (Rotterdam, The Netherlands), Avans University of Applied Sciences (Breda, The Netherlands) and with help from the organizations of the Bredase Singelloop, Rotterdam Marathon and Marathon Eindhoven.

Publication of this thesis was kindly supported by:

Fysiosupport
Kliniek ViaSana
PECE ZORG
Knie Expertise Centrum
Erasmus Medical Center
Avans Hogescholen
Annafonds
Nederlandse Vereniging voor Fysiotherapie in de Sportgezondheidszorg (NVFS)
Scientific College Physical Therapy (WCF) of the Royal Dutch Society for Physical Therapy (KNGF)
Nederlands Paramedisch Instituut (NPI)
Progress Educations

Author: Dennis van Poppel
Cover design: Bert Mutsaers
Infographic: Gijs Copic
Lay-out: Drukkerij Erhardt
Printing: Drukkerij Erhardt
ISBN:

Risk Factors for Lower Extremity Injuries in Recreational Runners

Risicofactoren voor blessures aan onderste extremiteit bij recreatieve hardlopers

Proefschrift

ter verkrijging van de graad van doctor aan de

Erasmus Universiteit Rotterdam

op gezag van de rector magnificus

Prof. dr. A.L. Bredenoord

en volgens het besluit van het college voor promoties.

De openbare verdediging zal plaatsvinden op
5 november 2021 om 13.00 uur

door

Dennis van Poppel

Geboren te Eindhoven

Erasmus University Rotterdam

Promotiecommissie

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“Papa, is dat voor je artikel?”

CONTENTS

Chapter 1

General introduction

Introduction

Due to several knee ligament injuries in contact sports, about 20 years ago, I underwent three anterior cruciate ligament reconstructions. As a result, I needed to find another way of doing sports and releasing my energy. I decided to start running and got affected with the "running disease". In the same timeframe I started working as a sport's physical therapist and the number of injured runners that visited my physical therapy practice was surprisingly high. I saw an annually repeating pattern in which the incidence of runners with injuries increased two to three months before a major running event in my hometown, the Marathon Eindhoven. This triggered me to start doing research to find out what was going on!

Health benefits and injuries

Running has become increasingly popular over the last years[1-3]. Almost 2 million people participated in running activities in the Netherlands in 2012[4]. Running has many positive effects on psychological and physical wellbeing. It leads to substantial improvements in public health and longevity[5]. Running is associated with reduced disability in later life and improves physical parameters and psychological vitality[6-12]. Despite the reported health benefits, injuries also occur, especially during the preparations before the running events, especially the longer events such as (half)marathons[13].

Running related injuries (RRIs) mainly occur in the lower extremities with incidence rates ranging from 7.7 to 17.8 per 1000 hours of running[14]. This variation in incidence is probably the result of differences in definition of injuries, measurement protocol and study populations. Study populations vary between track- and field runners, novice runners and experienced runners[14]. The predominant site of RRIs varies whereas knee injuries and Achilles tendon complaints are mentioned mostly with an incidence ranging from 2-32.5% for the knee, and 7.4-18.5% for the Achilles tendon[13,15,16].

Aetiology

Most studies examining RRIs are relatively small prospective cohort studies. As a result, there is a lack of evidence concerning the aetiology of RRIs. Several personal- or training related characteristics have been suggested to be related to RRIs[17-19]. But none of these factors on itself is sufficient enough to cause a RRI[20]. When evaluating causal mechanisms, it is suggested that researchers should focus on training-related characteristics as primary exposures of interest in a large prospective cohort studies[21]. However, training-related characteristic on itself are not consistent as training volume, duration, frequency, etc are variable while runners adapt their training programs to running events they subscribed. With the current knowledge a single factor analysis is insufficient and only a multifactorial model can give a comprehensive insight in the aetiology of RRIs (figure 1).

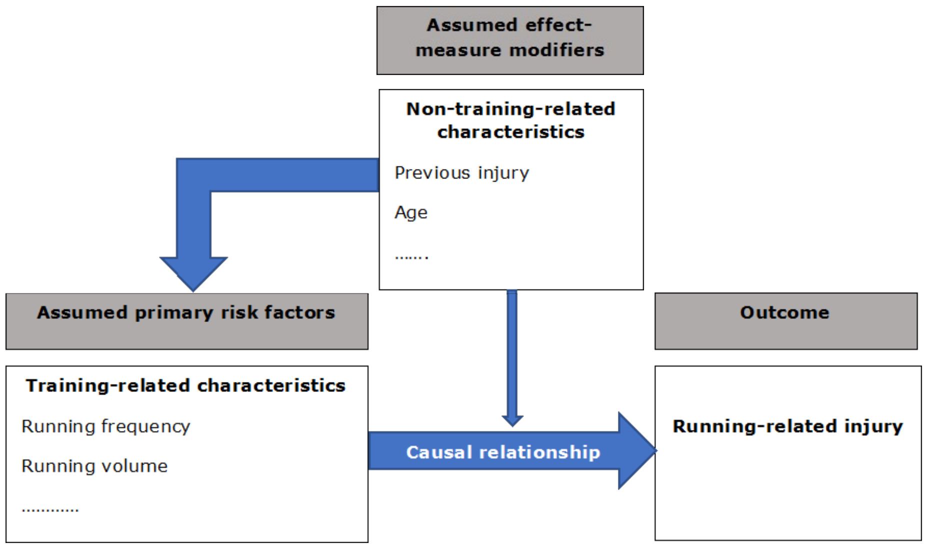

Figure 1; A model according Malisoux for determinants of RRIs

Risk factors

Many injured runners visit a general practitioner or (sports)physical therapist for prevention of injuries or treatment of the injury. It is unclear whether these rehabilitation- or injury prevention programs are meaningful while most running related (RRIs) are overuse injuries[22] and the aetiology of developing RRIs is still not fully understood. In order to create a successful injury prevention protocol for RRIs, the mechanism behind developing RRIs and potential risk factors should be identified.

The last decade many studies are targeted to identifying risk factors for RRIs and numerous possible risk factor have been described[23-29]. These studies were executed in either short- or long-distance runners, but none of them included both types of runners. It is not unlikely that risk factors are different between these groups, because demographic-, personal- and training related factors are different. For example, short-distance runners often have less running experience compared to long-distance runners. In order to determine whether risk factors for RRIs vary within these groups, we examined risk factors in both short- and long-distance runners in this thesis.

Previous systematic reviews described the results of risk factors for RRIs[17-19]. A wide range of personal-, training related- and health related possible risk factors have been described like age, body mass index (BMI), sex, running experiences, force distribution, types of shoes, training related characteristics (duration, frequency of running, training distance, running speed, warm-up, running terrain). In contrast to the dozens of possible risk factors, only limited evidence was found for some of these risk factors for RRIs. These systematic reviews evaluated risk factors for RRIs in general[17] and within subgroups of middle- and long-distance running[19] and sex differences[18]. Although a quality assessment of individual studies was performed, none of these studies judged the overall quality (or certainty) of the evidence. Therefore, we performed an updated systematic review using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE approach) in order to judge the overall quality of the evidence.

Knee injuries are the most common in RRIs. Up to date, no previous studies were performed to identify specific risk factors for knee injuries in short- and long distance runners. In this thesis a risk model for related knee injuries is developed.

Outline of this thesis

The objectives of this thesis are to determine the incidence and prevalence of RRIs and to identify risk factors for RRIs in recreational short- and long-distance runners. To answer these objectives this thesis contains 5 studies. In **Chapter 2** we describe the incidence, prevalence and course of lower extremity injuries during a 12 months follow up period in runners who participated in the Bredase Singelloop 2009 and were running from 5 km to half marathon distance. A systematic overview addressing risk factors for RRIs in presented in **Chapter 3**. In **Chapter 4** we present risk factors for lower extremity injuries in long-distance (half-marathon and marathon) runners of the Lage Landen Marathon Eindhoven 2012. In the prospective cohort study in **Chapter 5**, risk models for RRIs in short– and long-distance runners were determined within a group of almost 3700 runners, running 5km to marathon distance. In **Chapter 6** we present a risk model for running related knee injuries in recreational short- and long-distance runners. Finally, in **Chapter 7**, we discuss the main findings of this thesis and implications for clinical practice and further research.

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Chapter 2

Prevalence, incidence and course of lower extremity injuries in runners during a 12-month follow-up period.

Dennis van Poppel, Gwendolyne scholten-Peeters GG, Marienke van Middelkoop, Arianne P. Verhagen.

Scand J Med Sci Sports. 2014 Dec;24(6):943-9. doi: 10.1111/sms.12110. Epub 2013 Aug 19. PMID: 23957385.

Abstract

Objective: To describe the incidence, 12 months prevalence and course of lower extremity injuries occurred during and after the Amgen Singelloop Breda in 2009.

Design: Prospective cohort study

Setting: Population based

Participants: In total 3605 registered runners received a web-based baseline questionnaire of which 713 participants completed and returned it.

Assessment of incidence and prevalence: Information about previous injuries, training programs and demographic data were gathered at baseline. Site and intensity of running injuries and occurrence of new injuries, were obtained from 5 post-race questionnaires.

Main Outcome Measurements: Lower extremity injury.

Results: The incidence of running injuries during the Amgen Singelloop Breda itself was 7.8%; most of these injuries occurred in calve muscle, thigh and knee joint. Three months incidence of injuries during follow-up varied between 13.5%-16.3%. During the 12 month follow up period 277 new running injuries were reported. Runners who ran more than 10 km are more susceptible to injury in comparison with runners who ran short distances (10 km or less). In total 69.1% of running injuries resolves within 10 days.

Perspective: Running injuries are very common among recreational runners. Injuries mostly occur in knee, thigh and calf muscle.

Introduction

Long-distance running is becoming increasingly popular among recreational sports participants. Many health benefits of long-distance running have been reported, such as improvement of psychological vitality, endurance capacity and weight reduction[1,2]. Furthermore, long-distance running is associated with reduced disability in later life and a notable survival advantage[3]. Unfortunately, long-distance running can result in injuries and other physical impairments, probably as the result of overtraining[2,4].

Several studies evaluated the prevalence and incidence of lower extremity injuries in long-distance runners. In a Finnish retrospective study 143 (from 265) of the best Finnish long-distance runners reported acute injuries mainly to the foot, ankle and knee and overuse injuries in the foot and knee. Prevalence of all running injuries was 75% of which 28.7% were acute injuries and 59.4% were overuse injuries[5]. Among runners who participated in the Rotterdam marathon study (2008) 54.8% reported a lower extremity injury in a 12 months period before the marathon and the incidence during the marathon was 18.2%. This ambispective study only included male competitors[6].

A systematic review showed that the incidence of running related injuries varies between 19.4% and 79.3%[4]. Just half of all studies used a prospective design and only few were of good methodological quality. Almost all studies included athletes or the longest follow-up period was 6 months. Just three studies included recreational runners and used a follow up period of 12 months. But these studies have been done over twenty years ago[7,8,9]. Since then running has become increasingly popular, especially in recreational runners and possibilities to run and train have developed over time.

No recent studies prospectively evaluated running injuries in both long-distance runners and short-distance runners, described the course of injuries and had a follow up of at least one year. Only the Rotterdam Marathon study had a prospective design with a 3-month follow up period[10]. Because of planning in training programs and events it seems likely that incidence of lower extremity injuries varies during a year. It is unclear whether participants, who suffer from an injury during an event, are more likely to report new injuries during a 12 months follow up period, compared to participants without an injury.

Therefore, the aim of this prospective cohort study was to describe the prevalence, incidence and course of lower extremity injuries in recreational runners during a 12 months follow up period after the Amgen Singelloop Breda 2009.

Methods

Study participants

Participants of the Amgen Singelloop Breda (October 4th 2009) were included in the study. The Amgen Singelloop Breda is a run over different distances (5 km, 10 km, 15 km and 21 km) through the city of Breda, The Netherlands. It is a yearly local event.

Procedure

From the in total 8900 registered participants of the Amgen Singelloop Breda, all participants (3605) who subscribed by internet and registered their email addresses received an invitation to participate in the study. These runners received an invitation by email to fill-in a baseline questionnaire by email, one month before the Amgen Singelloop Breda (T0).

All participants who returned the baseline questionnaire received follow up questionnaires. The follow up questionnaires were sent one week after the run (T1), at 3 months (T2), 6 months (T3), 9 months (T4) and 12 months (T5) after the event. All participants received a reminder when the questionnaire was not returned within a week.

The Medical Ethical Committee of the Erasmus Medical Centre approved this study.

Questionnaires

Baseline questionnaire

Information about demographic variables, running activities and lower extremity injuries in previous 12 months was obtained from the baseline questionnaire (T0). Demographic variables consisted of gender, age and Body Mass Index (BMI).

Running activities were measured in terms of frequency (times a week), speed, duration (average running time), total amount of running distance per week and years of running experience. These were self-reported data by participants.

Follow-up questionnaires

The follow up questionnaires obtained information regarding running distance and new injuries occurred during the Amgen Singelloop Breda and during the 12 months follow-up period. Information comprised running distance, finishing the intended running distance and existence, duration, intensity and site of injuries. The site of the injury was reported

and pain intensity was measured using an 11-point Numeric Rating Scale (NRS)[11,12]. The questionnaires used were the same as in the Rotterdam Marathon Study[10].

The following definition of running injuries was used in baseline questionnaire and follow up questionnaires:

Self-reported complaints of muscles, joints, tendons or bones in lower extremity due to running activities. Complaints reduce running intensity or frequency, or injured runners need to have medical consultation[8].

Injuries were overall injuries, no difference was made in acute injuries or overuse injuries. The questionnaires are available by the author.

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS version 18, Inc, Chicago, Illinois). Descriptive statistics were used for baseline characteristics, prevalence and incidence of lower extremity injuries at all time points.

Prevalence was calculated as number of injuries per kilometers running distance per year. The incidence of injuries was measured within a week after the Amgen Singelloop Breda. To be sure all injuries were sustained during the event all participants were asked to report any injuries between baseline measurement and the start of the event, only new injuries were used for analysis. The first follow up questionnaire (T1) evaluated the incidence of participants with injuries after baseline measurement and prior to the Amgen Singelloop Breda and during the event. Incidence during the follow up period was determined as percentage of runners who reported new injuries in total amount of participants who returned the questionnaires after 3, 6, 9 and 12 months and the number of km needed to run to develop an injury.

Results

Baseline characteristics

In total 713 of the 3605 invited runners (19.8%) returned the baseline questionnaire. Figure 1 shows the number of the participants returning the follow up questionnaires during the follow up period. Characteristics of the participants are represented in Table 1. Of all participants 406 (56.9%) were male, the mean age was 42.5 years (SD, 11.5 years). Age and running experience were significantly ($P>0.05$) different between male en female runners. Average age of female runners was 39.1 years (range 13-67 years) and of male runners 50.0 years (10-77 years). Average running experiences of male runners was 11.4 years (range 0-48 years) and of female runners 6.1 years (0-39 years).

Figure 1: Flowchart Bredase Singelloop 2009

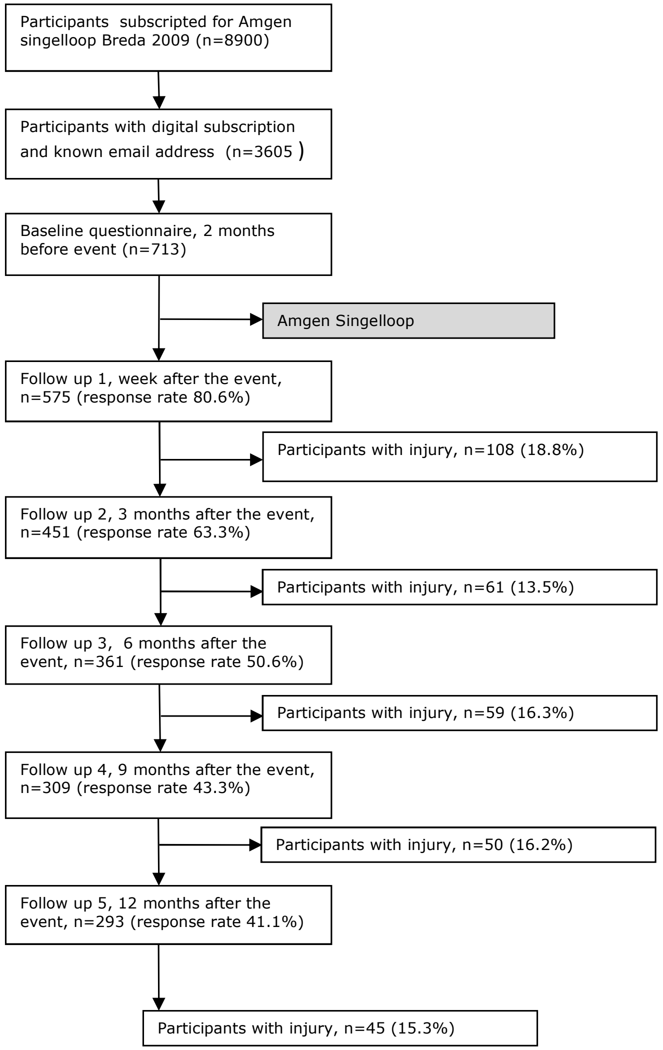

Table 1: Baseline characteristics of the participants of the Amgen Singelloop Breda

Participants	T0 (n=713)	T1 (n=574)	T2 (n=451)	T3 (n=357)	T4 (n=304)	T5 (n=291)
Demographic characteristics						
Gender (male/female)	406/307 56.9%/43.1%	337/237 58.7%/41.3%	268/183 59.4%/40.6%	219/138 61.3%/38.7%	180/124 59.2%/40.8%	181/110 62.1%/37.9%
Age in years (mean, sd)	42.5 (11.5)	43.0 (11.6)	43.5 (12.0)	43.8 (11.8)	44.0 (12.0)	44.5 (12.0)
Body Mass Index kg/m2 (mean, sd)	23.5 (2.4)	23.5 (2.4)	23.5 (2.4)	23.5 (2.4)	23.3 (2.3)	23.4 (2.3)
Running related characteristics						
Years of running experience in years (range)	9.1 (0-49)	9.2 (0-48)	9.7 (0-48)	9.5 (0-45)	9.1 (0-44)	9.5 (0-45)
Weekly distance in km (mean, sd)	22.2 (13.8)	23.0 (14.2)	23.0 (14.6)	23.1 (14.3)	23.1 (14.6)	22.6 (14.4)
Weekly duration in hours (mean, sd)	2.8 (1.6)	2.8 (1.6)	2.8 (1.6)	2.8 (1.6)	2.8 (1.6)	2.8 (1.6)
Frequency in times a week (mean, sd)	2.5 (0.9)	2.5 (0.9)	2.5 (0.9)	2.5 (0.9)	2.6 (1.0)	2.6 (1.0)
Running speed in km/hrs (mean, sd)	10.3 km/hrs (1.9)	10.4 km/hrs (1.9)	10.4 km/hrs (2.0)	10.4 km/hrs (2.1)	10.4 km/hrs (2.1)	10.4 km/hrs (2.1)

Almost half of the runners (46.3%) suffered one or more running injuries during the year preceding the baseline questionnaire. In total 704 injuries were registered by 330 participants. Site of these injuries is given in Table 2. From all injuries the knee was reported most frequently (20.9%), followed by calve (16.3%) and Achilles tendon (12.2%). At the time of the baseline questionnaire 261 injuries were reported.

One week after the event (T1)

Out of the 713 runners who returned the baseline questionnaire, 575 (80.6%) runners returned the first post-race questionnaire (T1). In total 76 participants (13.2%) ran 5 km, 281 participants (48.9%) 10 km, 93 participants (16.2%) 15 km and 124 participants (21.6%) ran 21 km, 6 were missing. In total 538 (94%) participants started and finished, 8 participants started but did not finish, 27 participants did not start because of sickness or injuries, and 2 were missing.

In total 105 participants that returned T1 (18.3 %) reported at least one new injury between T0 and before the start of the Amgen Singelloop Breda, 84 of these started despite the injury and finished, 2 started but did not finish and 18 participants did not start because of sickness and injuries.

In total 108 participants (108/575; 18.8%) reported at least one injury during the Amgen Singelloop Breda, of which 45 were new injuries were. Therefore the incidence of injuries during the event is 7.8% (45/575).

Of all participants reporting injuries during the event, 62 participants ran short distances (5 km and 10 km), 46 participants ran long distances (15 km and the 21 km). Most of the injuries occurred in calf muscle (n=22), hip (n=20) and knee (n=30) (Table 2).

There were some differences in the site of injuries between runners participating in short distance and long distance. In short distances (5 km and 10 km) injuries in the knee (18.5%), calf (16.3%) en Achilles tendon were mostly reported while longer-distance runners (15 km and 21 km) reported most injuries in the knee (19.7%), hip (15.2%) and thigh (13.6%).

In runners with more than 5 years of running experience also mostly reported injuries were the knee (19.4%), calf (13.9%) and Achilles tendon (13.9%). In runners with less than 5 years of running experience the number of injuries to the knee (18.6%), shin (15.1%) and calf (14.0%) were mostly reported.

In female runners most injuries occurred in the knee (22%) followed by shin (13.8%), calf (13.8%) and hip (13.8%). Also in male runners most injuries occurred in the knee (16.5%) followed by the Achilles tendon (16.5%) and calf (14.1%).

No significant differences were found between healthy runners and runners which reported an injury.

Follow up T2-T5

The incidence of injuries was measured every 3 months. During the 12 months follow up period 277 new injuries were reported by 215 runners. One injury occurred in 1303 km and the mean incidence of injuries was 16.3%.

Three months after the event, 81 new injuries were reported by 61 participants [13.5%, (61/451)], at 6 months 84 injuries were reported by 59 participants [16.3%, (59/361)],, at 9 months 51 injuries were reported by 50 participants [16.2 %, (50/309)], and at 12 months 61 injuries were reported by 45 participants [15.3 %, (45/293)]. The site of injuries is given in Table 2.

Pain intensity of injuries

The mean pain intensity was 4.31 (SD 2.03) on the NRS. The range varied from 1 to 9 and modus was 3 (n=84).

Of all participants who reported an injury after the run and returned the follow up questionnaires (n=97) 69.1% of the participants reported a full recovery of injuries within 10 days.

Complete case analysis

In total 293 participants returned the final follow up questionnaire at 12 months of which 167 participants returned all questionnaires during the follow up period. Of these, 97 participants reported no new injuries at all during the 12 months period. Twenty-three participants reported a new injury in the Amgen Singelloop 2009, 15 participants at 3 months, 16 participants at 6 months, 23 participants at 9 months and 30 participants at 12 months.

Forty-three participants once reported an injury, 19 reported an injury twice, 5 reported an injury three times, 3 reported an injury four times and nobody reported an injury on all measurements. Incidence of lower extremity injuries is 41.9% (70/167).

Most reported site of injury was the knee (n=24), hip (n=12) and calves (n=12).

Table 2: Site of injuries

Site of injury	Injuries year before baseline N= (%)*1	Injuries at baseline N= (%)*2	Injuries between baseline and T1 N= (%)*3	Injuries during event (T1) N= (%)*4	Injuries at T2 N= (%)*5	Injuries at T3 N= (%)*6	Injuries at T4 N= (%)*7	Injuries at T5 N= (%)*8
Hip	62 (8.8%)	20 (7.7%)	15 (10.0%)	20 (12.7%)	9 (11.1%)	8 (9.5%)	6 (11.8%)	5 (8.2%)
Groin	38 (5.4%)	9 (3.4%)	4 (2.9%)	5 (3.2%)	1 (1.2%)	7 (8.3%)	0 (0%)	1 (1.6%)
Thigh	49 (7.0%)	28 (10.7%)	13 (9.4%)	18 (11.4%)	4 (4.9%)	10 (11.9%)	5 (9.8%)	4 (6.6%)
Knee	147 (20.9%)	57 (21.8%)	33 (23.9%)	30 (19.0%)	21 (25.8%)	23 (27.4%)	18 (35.3%)	19 (31.1%)
Shins	59 (8.4%)	14 (5.4%)	11 (8.0%)	17 (10.8%)	2 (2.4%)	2 (2.4%)	1 (2.0%)	6 (9.8%)
Calve	115 (16.3%)	35 (13.5%)	15 (10.9%)	22 (13.9%)	9 (11.1%)	13 (15.5%)	7 (13.7%)	5 (8.2%)
Achilles tendon	86 (12.2%)	36 (13.8)%	15 (10.9%)	18 (11.4%)	8 (9.9%)	9 (10.7%)	3 (5.9%)	6 (9.8%)
Ankle	53 (7.5%)	23 (8.8%)	12 (8.7%)	8 (5.0%)	10 (12.3%)	4 (4.8%)	4 (7.8%)	5 (8.2%)
Foot	65 (9.2%)	30 (11.5%)	17 (12.3%)	15 (9.5%)	12 (14.8%)	7 (8.3%)	7 (13.7%)	9 (14.8%)
Toes	30 (4.3%	9 (3.4%)	3 (2.2%)	5 (3.2%)	5 (6.2%)	1 (1.2%)	0 (0%)	1 (1.6%)
	704	261	138	158	81	84	51	61

*1 and *2 reported by 330 injured runners; *3 reported by 105 injured runners, *4 reported by 108 injured runners, *5 reported by 61 injured runners, *6 reported by 59 injured runners, *7 reported by 50 injured runners, *8 reported by 45 injured runners.

Discussion

This is the first prospective cohort study with a follow up period of one year and a population of long-distance and short-distance recreational runners combined.

The one year incidence of running injuries in our study is one injury in 1303 km. The mean 3-month incidence was 16.3%. It is unclear whether differences in follow up period are really present while they are only small. Up to 3 months after an event incidence seems to decrease and 6 months prior to an event starts to increase again. A possible explanation could be that runners decrease their running activities after an event and intensify their running activities 6 months before an event. Although, this is probably only relevant in participants who take part in one or two events. If participants take part in several events, training will be performed more consistently. By analyzing our population there seems to be a trend that during the follow up period the relative amount of people who do run at least one other event increases.

Nevertheless, incidence of running injuries remains rather stable.

We were unable to gathered information about changes in training schedules during the follow up period, so bias in results because of changes in training schedules cannot be ruled out.

We measured severity of injuries by using and NPRS. The average NPRS score was 4.31. This could explain why most injuries resolve in 10 days because intensity is low and most injuries are minor injuries.

To assess running speed, we used a self-reported questionnaire. Runners are often very precise in assessing their running speed and distance during training. Nowadays, a lot of schedules are used in training, and time/distance measurements can be done easily and objective by applications or internet. Therefore, we do not think that this would lead to considerable bias.

Comparison with other studies

Several authors retrospectively describe the prevalence of lower extremity injuries. In our study prevalence of injuries 12 months before the Amgen Singelloop Breda was 46.3% and was in line with the results from recent studies [5,10,13-16]. The incidence of running injuries during the event (7.8%) was lower than the incidence in the Rotterdam marathon study (18.2%). Possible explanations for these differences are the different study populations. In our study no marathon runners were included. It is possible that the lower incidence of running injuries can be explained by the relative shorter distances participants ran, through which overuse was less common.

In this study incidence of injuries in participants who ran longer distance is 21.6% while incidence in participants who ran short distances is 15.8%. A possible explanation could be that most injuries in runners are overuse injuries which are more likely to occur in long-distance running in comparison with short distance running, but because of our small sample size this difference might also occur by chance.

In the literature, the most reported location of lower extremity injuries in runners is the knee joint [8,10,13,17]. Lower extremity injuries during the Amgen Singelloop Breda mostly occurred in calf muscle, thigh and knee. This is in line with other studies[8,10].

Strength and limitations

The most important strength of our study is the prospective design with 12 months follow up period. Furthermore, our population exists of recreational runners and various running distances. Most other studies concern marathon runners or short distance runner, but not both, and have a short follow up[3,6,10,13-15,17-20]. Therefore our results can be better generalized to the majority of runners.

One of our limitations is the low response rate at baseline of 19.8% (713/3605) and the high dropout rate during the follow up period. A high dropout rate could be expected while a follow up period was used of 12 months. For example participants could have lower commitment during the follow up period or changed their emailadress. Authors acknowledge this could have resulted in bias but at this moment no good alternatives are present how to deal with such amount of dropout. In regard of this problem also a complete case analysis was done.

Because of the lost to follow up incidence was counted as percentage of participants with new injuries in all participants who returned the follow up questionnaires per moment in time.

Prevalence and incidence could have been slightly over-reported. Participants with injuries could be more committed to return questionnaires during the follow up period. In this study no differences were found between follow up groups. Prevalence was calculated as number of injuries per kilometers running distance per year. This was reported at baseline. Our assumption was that participants reported their average running distance a week during a 12 months period.

According to the definition of injuries, an injury is evident when running activities are restricted for one week. Exact diagnosis of injuries remains unknown. Although there was no systematic physical investigation in this study, authors had a good insight into self-reported pain and discomfort of running injuries reported by runners themselves.

Response rates for email surveys are known to be lower than paper and pencil surveys[21]. This can be an explanation for the low response rates in our study. Selection bias could not be ruled out because people who are injured are possibly more motivated to participate in the study. Potential recall bias could be present because participants were asked information about a 3 months period.

The validity of information, for example the severity of injuries, and running speed should be questioned as these have been measured by self-reported questionnaires. These measures are not validated and could have caused some bias. Participants may apply the criteria for answering the questions differently. Therefore our results should be interpreted with caution.

Perspective

Running injuries are very common among recreational runners. Injuries mostly occur in knee, thigh and calf muscle. Incidence of running related injuries varies from 14.2% to 17.2% during a 12 months follow up period.

In future research, large prospective cohort studies should be carried out to enable subgroup analysis. Relevant specific groups are short- and long-distance runners, recreational or competitive runners, novice or experienced runners.

What are the new findings?

- Mean 3 month incidence is 16.3%
- By far, most injuries occur in the knee
- Runners running relative longer distances (15 km or 21 km) could be more susceptible to injury than runners who run other short distances
- 69.1% of running injuries resolves within 10 days

How might it impact on clinical practice in the near future?

- In most running injuries there is no indication for treatment while most injuries resolve by natural recovery
- Subgroups should be made in future research to find risk factors for specific running distances and location of injuries

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Chapter 3

Risk factors for overuse injuries in short- and long-distance running: A systematic review.

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J Sport Health Sci. 2021 Jan;10(1):14-28. doi: 10.1016/j.jshs.2020.06.006. Epub 2020 Jun 12. PMID: 32535271.

Abstract

Introduction: The aim of this study was to review information about risk factors for lower extremity running injuries in both short- (mean running distance of ≤20km/week and ≤10km/session) and long-distance runners (mean running distance of >20km/week and >10km/session).

Materials & Methods: Electronic databases were searched until February 2019. Prospective cohort studies using multivariable analysis for the assessment of individual risk factors or risk models for the occurrence of lower extremity running injuries were included. Two reviewers independently selected studies for eligibility and assessed risk of bias with the Quality in Prognostic Studies tool. The GRADE approach was used to assess the quality of the evidence.

Results: Twenty-nine studies were included; 17 studies included short-distance runners, 11 studies included long-distance runners and one study included both types of runners. A previous running related injury was the strongest risk factor with moderate quality evidence for an injury in long-distance runners. Previous injuries not attributed to running, was the strongest risk factor with high quality evidence in short-distance runners. Higher Body Mass Index, higher age, sex (male), having no previous running experience and lower running volume were strong risk factors with moderate quality evidence for short-distance runners. Low quality evidence was found for all risk models as predictor for running related injuries in short- and long-distance runners.

Conclusion: Several risk factors have been identified among short- and long-distance runners but the quality of evidence for these risk factors for RRIs is limited. Running injuries seem to have a multifactorial origin both in short- and long-distance runners.

Introduction

Running is one of the most popular physical activities around the world to achieve or maintain a better physical health[1]. In the last ten years, the number of runners has doubled and this number is still increasing[2]. Running is beneficial for the whole body: it improves endurance, decreases the risk of cardiovascular diseases and helps to lose weight[3-4]. Unfortunately, running is also associated with a high risk of injuries, especially in the lower extremities[5]. About 80% of running related injuries (RRIs) are related to overload[6,7]. Mainly tendons and ligaments are at risk due to the relative slow adaptation to training load[7].

Due to many different injury definitions and running types, the incidence of RRIs varies considerably[8,9]. Runners have a high risk of getting injured with incidence rates ranging from 7.7 to 17.8 per 1000 hours of running[6]. The incidence of running injuries differs between different running distances. Short-distance runners (15 km running or less) have an incidence ranging from 14.3-44.7% while long-distance runners (half-marathon or marathon) seem to have more injuries 16.7-79.3%[10].

Several risk factors for RRIs are described[11,12]. These risk factors can be divided into personal factors (e.g. age, weight, height), training-related factors (e.g. distance, frequency, intensity, shoes) and health-related factors (e.g. medication, previous injury, use of alcohol)[10]. According to recent systematic reviews, a previous injury is the most important risk factor in short- and long-distance runners[10,12]. The use of orthotic inserts in shoes and hip abductor weakness are associated with an increased injury risk as well[10-13]. Inconsistent findings were found for other risk factors, such as Body Mass Index (BMI)[14-16], age[15,17] and training distance[18-20]. Nonetheless, none of these risk factors have been conclusively found as a cause of a particular RRI. Also particular injuries may not be related to a single risk factor but an interaction of several risk factors.

Previous studies have indicated that risk factors vary for different populations of runners[10,12,16]. For instance, it seems that inexperienced runners are twice as likely to get injured compared to experienced runners and that men and women have different risk profiles[9-10, 21]. In addition, studies with short-distance runners revealed other risk factors than studies with marathon runners[22,23]. One study showed that short-distance runners seem to be at higher risk of injury with a BMI>30, an age between 45-65 years, a non-competitive behaviour and a previous injury[22]. Other studies found that long-distance runners seem to be at higher risk for a RRI when their BMI>26 and those who had a previous injury, whereas older age, performing interval training and running more training kilometres per week were found to be protective[19,23-24].

As personal, training-related and health-related factors such as age, ratio of female/male runners, km of running per week, and running experience differ between short- and long-distance runners[22-24], we hypothesize that also risk factors for short- and long-distance

RRIs will differ between these groups. None of the previous reviews explicitly addressed these differences in short- and long distance recreational runners and described separate risk factors for short- and long-distance runners. Moreover, none of the previous systematic reviews used the GRADE to judge the overall quality of evidence and included both individual risk factors and risk models for short- and long-distance RRIs.
In order to develop injury prevention strategies for recreational runners, identifying risk factors is important[25]. If risk factors vary per distance, injury prevention strategies between short- and long-distance runners should be different. Therefore, the aim of this systematic review is to evaluate risk factors for lower extremity running injuries for short- and long-distance recreational runners separately.

Materials & Methods

Protocol and registration

The review was prospectively registered with PROSPERO (registration number CRD42019133799). This review is written in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[26].

Data Sources and Search Procedure

Electronic searches were performed by a librarian (SvdH) from inception until February 2019 in PubMed, CINAHL, Cochrane Library, SPORTDiscus and PsychINFO with MESH-terms and free text words. To identify relevant studies, the several RRI related terms were used (Appendix A). Terms to evaluate the study design were: cohort, prospective, observational and longitudinal studies. Details of the search strategy are available in Appendix A. References in the included articles were checked for relevant papers.

Study Selection

Studies were included/excluded if they met the selection criteria reported in Appendix B. Two reviewers (AS,MvdW) independently screened titles and abstracts using the selection criteria. Full text articles of all the selected studies were retrieved and independently assessed by the two reviewers applying the selection criteria (see Appendix C). Disagreement was resolved by consensus. When no consensus could be reached, a third reviewer (DvP) made the final decision.

Risk of Bias Assessment

All risk factor studies were assessed for Risk of Bias (RoB) by two reviewers independently (MvdW,AS) using the 'Quality In Prognostic Studies tool' (QUIPS)[27]. For risk model studies RoB was determined using the PROBAST (Prediction model Risk Of Bias Assessment Tool)[28]. Disagreement was resolved by consensus. A third reviewer (DvP) made the final decision in case no consensus could be reached.

Data Collection and Processing

The following data were extracted from the included studies: year of publication, follow-up period, population characteristics (age, body mass index or weight and height, sex), running distance, number of participants included and number of participants analysed, the definition of an injury, number of RRIs, the type of injury and risk factors, whether the studies evaluated a risk model or not and adjusted for confounders. The data were processed in a data extraction table. All studies were classified as short-distance (mean running distance of ≤20km/week and ≤10km/session) or long-distance (mean running distance of >20km/week and >10km/session). If km/week conflicted with km/session, for instance 40km/week with a frequency of 5 times/week, it was classified according to km/week. In case the study population consisted of only males (or females), or when the results in a mixed population were analysed separately, the results for males and females were also described separately.
Risk factors presented in each study were extracted and categorized as personal, training-related or health-related factors, for short-distance runners and long-distance runners separately. Outcome data was extracted, such as: Beta's, Odds Ratios (OR), Relative Risk Ratios (RR) and Hazard Ratios (HR) and explained variance (R^2) or area under the curve (AUC) for risk models.
The results per potential risk factor are presented in following subgroups; general (if no subgroups in sex were made), male and female.

Outcome

The main outcome variable was an RRI, defined as: self-reported musculoskeletal complaints, in the lower extremity, caused by running activities[23].

Data Synthesis

We summarized the findings using tables, figures, and text and distinguished three categories for the short- and long-distance recreational runners: males, females and the total general group. Meta-analysis could not be performed due to clinical heterogeneity with respect to population and definition of outcome(s).
Cohen's kappa was used to determine the interobserver agreement of the RoB assessment .
The GRADE approach was used to judge the overall quality of evidence into high, moderate, low and very low quality. This provides insight into the confidence of the

estimate of the effect. In the field of prognosis, longitudinal cohort studies, initially provides high quality evidence and can be downgraded or upgraded[29-35].

Six study characteristics downgrade the quality of evidence (phase of investigation, study limitation, inconsistency, indirectness, imprecision, publication bias), and two study characteristics upgrade the quality of evidence; large (OR>2 or <0.5) or very large effect size (OR>5 or <0.2) and exposure-response gradient[29-35]. Concerning study limitations the evidence was downgraded when <75% of the participants were in low RoB studies. Limitations regarding imprecision were determined by the width of the 95% confidence interval (CI) and sample size (N=at least 2,000-4,000)[32]. Limitations in indirectness were reported if the outcome variable was not fully appropriate (e.g. when an outcome was not general for running related injuries but specific patellar femoral pain syndrome) or study populations differed[34]. Inconsistency was present if the direction of effect differed (protective versus risk factor, or no effect) between studies or when differences in risk estimates were found[33]. Lastly, the evidence was upgraded when >75% of the participants found large effect sizes (OR>5 or <0.2)[35]. Single studies (n<4,000) start at low quality evidence because of downgrading by inconsistency and imprecision[32,34].

If most of the studies, including >50% of the participants, found no significant association, results were described as evidence for **not** being a risk factor. If most of the studies, including >50% of the participants, found a significant association a potential factor is described as risk factor or protective factor depending on the association that was found.

Results

Study selection

A total of 1300 hits were identified from the literature electronic search and 1 article was retrieved from the reference list; 53 duplicates and 1163 articles were excluded based on titles and abstracts. Of the remaining 85 hits, another 49 articles were excluded based on full-text screening for several reasons. Finally, 29 studies with a total of 18,853 participants were included in this review, 25 studies presented risk factors (single factor studies) and 4 studies presented risk models (risk model studies) (Figure 1).

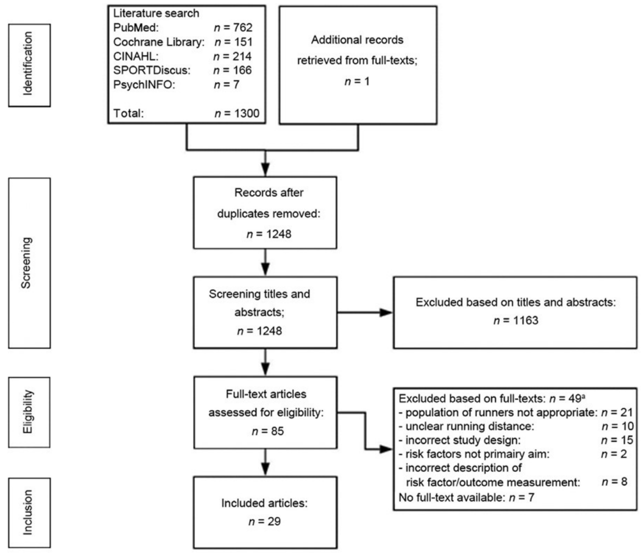

Figure 1: Flowchart of the literature search

Risk of Bias Assessment

The RoB in the domains 'outcome measurement' and 'prognostic factor measurement' was low. The domains 'study attrition' and 'study confounding' showed the highest RoB, mainly due to insufficient reporting (Table 1, Figure 2). The Kappa for the overall interobserver agreement (using the QUIPS) between the two reviewers was 0.80 (95%CI 0.75-0.83).

According the PROBAST, three risk model studies (23,24,56) had a low RoB and a good applicability. One risk model study[19] had problems with the applicability as only male runners were included.

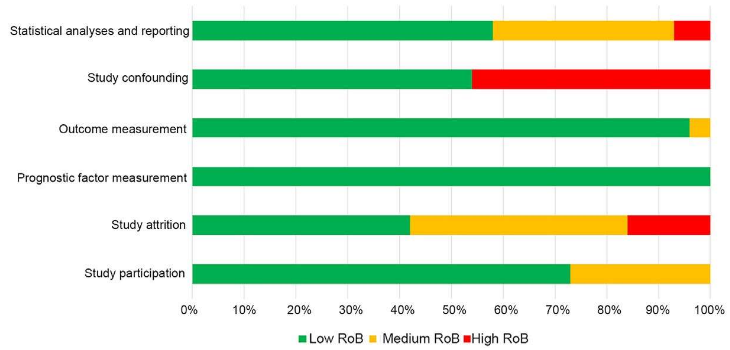

Figure 2: Risk of Bias

Table 1: Rating for individual studies.

References	Study Participation	Study Attrition	Prognostic Factor Measurement	Outcome Measurement	Study Confounding	Statistical Analyses and Reporting
Buist[2], 2010 (14)	L	M	L	L	L	L
Kluitenberg, 2016 (15)	L	L	L	L	H	L
Kluitenberg, 2015 (16)	L	M	L	L	L	L
Worp, 2016 (20)	L	M	L	L	L	L
Nielsen, 2013 (22)	L	L	L	L	L	L
Bredeweg, 2013 (36)	M	L	L	L	L	M
Buist[1], 2010 (37)	L	M	L	L	L	L
Hesar, 2009 (38)	L	L	L	L	H	M
Malisoux, 2015 (39)	M	H	L	L	H	L
Nielsen[1], 2014 (40)	L	M	L	L	L	L
Nielsen[2], 2014 (41)	L	L	L	L	L	L
Ramskov, 2015 (42)	L	M	L	L	H	L
Thijs, 2008 (43)	L	H	L	L	H	M
Thijs, 2011 (44)	M	L	L	L	H	M
Ginckel, 2009 (45)	L	L	L	L	H	H
Napier, 2018 (46)	L	L	L	L	L	L
Taunton, 2003 (47)	L	L	L	L	L	H
Brund, 2017 (48)	L	M	L	L	L	L
Hespanhol Junior, 2013 (49)	L	M	L	L	H	L
Hespanhol Junior, 2016 (50)	M	L	L	L	H	L
Hirschmüller, 2012 (51)	L	H	L	L	H	M
Hotta, 2015 (52)	M	M	L	L	L	M
Kelsey, 2007 (53)	L	H	L	L	L	M
Reinking, 2007 (54)	M	M	L	M	H	L
Messier, 2018 (55)	M	H	L	M	H	L

L: Low risk of Bias, M: Medium risk of Bias, H: High risk of Bias.

Study characteristics

Population

Seventeen studies examined risk factors (single factor studies) in short-distance runners[14-16,20,22,36-47], no risk model studies were found for short distance runners. Eight studies examined risk factors (single factor studies) in long-distance runners[48-55] and three were risk model studies[19,23,56]. One study examined short- and long-distance runners in a risk model study[24].
Table 2, 3 and 4 describe the characteristics of included studies.

Follow-up

In studies in short distance runners, the follow-up period ranged from 6 weeks to 1 year. The proportion of analysed participants ranged from 69-100% of the included participants at baseline. In studies in long-distance runners, the follow-up period ranged from 4 weeks to 2 years. The proportion of analysed participants ranged from 67-100% of the included participants at baseline.

Risk factors

A total of 38 potential risk factors were analysed in short distance runners and 36 in long- distance runners (see summary Table 5 and Appendix D-F). The overall results (GRADE approach) for risk factors in short- and long-distance runners are summarized in appendix G. Risk factors evaluated in more than one study are described in the text below.

Short-distance runners

Personal factors

Age. Six studies evaluated age as a potential risk factor[14,16,20,22,37,47]. In a generic population two studies (low RoB) found no association[20,22], and one study (low RoB) found higher age to be a risk factor (HR:1.02)[16]. There is therefore moderate quality evidence (downgraded for inconsistency) for age being a risk factor for RRIs.
One study (low RoB) found higher age to be a protective factor for injuries in male runners[37]. In a female population two studies (low RoB) found no association[14,37]. One study (medium RoB) found higher age to be a risk factor[47]. In males, there is low quality evidence (single study, downgraded for inconsistency and imprecision) that higher age is a protective factor, while in females we found low quality evidence (downgraded for limitations in design and inconsistency) that age is not a risk factor.
BMI. Six studies evaluated BMI as a potential risk factor[14,16,20,22,37,47]. In a generic population two studies (low RoB) found no association[20,22], and one study (low RoB)

found higher BMI to be a risk factor[16]. We found moderate quality evidence (downgraded for inconsistency) for BMI being a risk factor. One study (low RoB) found higher BMI to be a risk factor for injuries in female runners[37]. In a male population one study (low RoB) found no association[37], one study (low RoB) found higher BMI to be a risk factor[14] and another study (medium RoB) found higher BMI (>26kg/m2) to be a protective factor[47]. In females we found low quality evidence (single study, downgraded for inconsistency and imprecision) that higher BMI is a risk factor, and low quality evidence (downgraded for limitations in design and inconsistency) for BMI as a risk factor in male short-distance runners.

Running experience. Four studies evaluated previous running experience[16,20,22,37]. In a generic population two studies (low RoB) found no association[20,22]. One study (low RoB) found no running experience to be a risk factor for RRIs[16]. We found moderate quality evidence (downgraded for inconsistency) that having no previous running experience is a risk factor for RRIs.

One study (low RoB) found a significantly higher risk of injury in male and female runners when they had no previous running experience[37]. We found low quality evidence (single study, downgraded for inconsistency and imprecision) that having no previous running experience is associated with an increased injury risk in male and female runners.

Previous sports activity. A type of previous sports activity was included as a risk factor in six studies[14,16,20,22,37,47]. In a generic population no association was found[16,20,22]. We found high quality evidence that previous sports activity is not associated with RRIs.

One study (low RoB) found a significant higher injury risk in males when previous sports activities without axial loading were performed[14], while one study (one low RoB) found no association in males but a higher injury risk in females[37], and one study (medium RoB) did not provide data[47]. We found low quality evidence (single study, inconsistency and imprecision) for previous sports activity being a risk factor for RRIs in females and males.

Behaviour (competitive/hyperactive versus relaxed/laid back) was included as a risk factor in two studies[14,22]; one in a generic population[22] and one in males only[14]. One study (low RoB) found behaviour (relaxed/laid back) a significant risk factor[22], the other study (low RoB) found no association in males[14]. We found low quality evidence (single study, downgraded for inconsistency and imprecision) that behaviour a risk factor for RRIs in a generic population, low quality evidence (single study, downgraded for inconsistency and imprecision) for behaviour not being a risk factor in men.

Four studies included foot morphology (plantar arch index, navicular drop or foot pronation) as a potential risk factor[14,20,41,47]. Two studies (low RoB) were performed in the generic population[20,41]. One study found no significant association[20] and the other one revealed that runners with pronated feet had significantly fewer RRIs per 1000 km running compared to runners with normal feet[41]. We found low quality evidence (downgraded for inconsistency and imprecision) for foot morphology (moderate foot pronation) not being a risk factor for RRIs.

One study (medium RoB) did not present data on the plantar arch as a possible risk factor[47]. One study (low RoB) found that normal navicular drop was a protective factor for RRIs compared to a high navicular drop in female runners[14]. We found low quality evidence (single study, downgraded for inconsistency and imprecision) for foot morphology (normal navicular drop versus increased navicular drop) as a protective factor for RRIs in females.

Training related factors

Running frequency. Three studies included running frequency as a potential risk factor[15,39,47]. In a generic population two studies (medium and high RoB) found no association for running frequency and RRIs in the generic population[15,39]. We found moderate quality evidence (downgraded for study limitations) for running frequency not being a risk factor for RRIs. One study (medium RoB) found that running 1 day per week or less is associated with an increased risk for RRIs in females. We found very low quality evidence (single study, downgraded for study limitations, inconsistency and imprecision) for running frequency as a risk factor for RRIs in females[47].

Running weekly volume. Two studies included weekly volume (min per week) as a potential risk factor[15,39]. One study (medium RoB) found a weekly volume of >60 minutes to be a protective factor[15] and the other (high RoB) found a weekly volume of <2 hours to be a risk factor for injuries[39]. We found moderate quality evidence (downgraded for study limitations) that lower weekly training volume is a risk factor.

Running weekly distance. Two studies included weekly running distance as a potential risk factor[20,40]. One study (low RoB) found no associations between weekly running distance and injuries[40], while one study (low RoB) found a higher running distance (>30 km per week) a risk factor for RRIs. We found low quality evidence (downgraded for inconsistency and imprecision) for running distance as a risk factor.

Type of terrain. Two studies included type of terrain as a potential risk factor[20,47]. One study in a generic population (low RoB) found no significant associations between type of terrain and injuries in short-distance runners[20]. We found low quality evidence (single study, downgraded for inconsistency and imprecision) that type of terrain is not a risk factor. The other study reported no data on this risk factor[47].

Running shoe age. Three studies included running shoe age as a potential risk factor[16,20,47]. Two studies found no association[16,20] in a generic population. We found high quality evidence that running shoe age is not a risk factor for RRIs. One study (medium RoB) found running shoe age (4-6 months old) (as compared to 1-3 months, 7-12 months or 1-2 years) is a protective factor in male runners and a risk factor in female runners[47]. There is very low quality evidence (single study, downgraded for limitations in design, inconsistency and imprecision) that running shoe age is a protective factor in male runners and a risk factor for running related injuries in female runners.

Hip strength. Two studies included hip abduction strength as a potential risk factor[42,44]. One study (medium RoB) in a generic population found hip abduction strength as a risk factor for RRIs (very low quality evidence (single study, downgraded for study limitations, inconsistency, indirectness and imprecision)[42]. The other study (high RoB) did not present data on this association[44].

Intrinsic gait-related factors. Three studies included intrinsic gait related factors as risk factors[38,43,45]. All studies assessed different kinds of risk factors. One study (high RoB) found a significantly more laterally directed force distribution underneath the forefoot at forefoot flat and significantly decreased total displacement of the center of force (COF) as risk factors for the development of Achilles Tendinopathy[38].

One study (medium RoB) found force distribution was significantly more laterally directed at first metatarsal contact and at forefoot flat[38]. Furthermore, mediolateral force ratio showed more displacement of the force from medial to lateral in the initial contact phase. During the forefoot contact phase and the foot flat phase, the COF was more laterally directed in the injured group. At heel-off the x-component of the COF is situated significantly more laterally. During the forefoot push-off phase the x-component of the COF is situated significantly more medially. The velocity of the mediolateral and the anteroposterior displacement of the COF at forefoot flat was significantly slower. Anteroposterior displacement of the COF at forefoot flat was significantly higher in the injured group. Absolute force time integral underneath metatarsal five was significantly higher in the participants who sustained a RRI[45]. One study (high RoB) found a significantly shorter time to the vertical peak force underneath the lateral heel as a predisposing factor for patellofemoral pain syndrome but no risk estimates were presented[43].

In conclusion, there is very low quality evidence based on single studies (downgraded for study limitations, inconsistency, indirectness and imprecision) that intrinsic gait related factors are risk factors for RRIs.

Peak force. Two studies included active peak of ground reaction force as a potential risk factor[36,46]. One study (moderate RoB) published no data on this positive association[36] and one study (low RoB) found no association in females[46]. We found low quality evidence (single study, downgraded for inconsistency and imprecision) that active peak is not a risk factor for RRIs in a female population.

Table 2: Description of participants, injury type and definition and risk factors in single factors studies in short distance runners

Author, year of publication	follow-up	Included/Analysed (%), Injured (N)	Age (yr) mean ± sd	Sex (m/f)	BMI (kg/m²) mean (sd)	Running type	Injury definition	Risk or protective factor(s)	Type of injury
Buist[2], et al. 2010 (14)	13 weeks	603/532 (88%) Injured: 100	M: 42.3 (9.9) F: 37.9 (9.9)	226/306	M: 25.9 (3.3) F: 24.2 (3.4)	Short-distance: Novice runners training for a 6.7 km event	Running-related MSC of lower extremity or back, causing a restriction of running, for at least 1 week	Demographic variables, training characteristics and kinematic variables	Overall running-related injuries
Kluitenberg, et al. 2015 (15)	6 weeks	1772/1696 (96%) Injured: 185	43.3 (10)	364/1332	25.5 (4)	Short-distance: start-to-Run program of 20 minutes	MSC of lower extremity or back attributed to running and hampered running ability for 3 consecutive training sessions	Sociodemographic variables	Overall running-related injuries
Kluitenberg, et al. 2016 (16)	6 weeks	1772/1696 (96%) Injured: 159	43.3 (10)	364/1332	25.5 (4)	Short-distance: start-to-run program of 20 minutes	MSC in a sole body part of lower extremity or back attributed to running and caused a restriction in running ability for at least 3 consecutive training sessions (i.e. 1 week)	Running intensity, running frequency and running volume	Overall running-related injuries
Worp, et al. 2016 (20)	3 months	433/417 (96%) Injured: 93	38.7 (11.5)	0/417	23.2 (2.9)	Short-distance: 5-10 km start-to-run	Running-related pain lower back and/or lower extremity that restricted running for at least 1 day	Training distance and previous injury	Overall running-related injuries
Nielsen, et al. 2013 (22)	1 year	933/930 (100%) Injured: 254	37.2 (10.2)	468/462	26.3 (4.4)	Short-distance: novice runners with a self-structured runner program	MSC of lower extremity or back caused by running, which restricted the amount of running for at least 1 week	Demographic and behavioural factors	Overall running-related injuries
Bredeweg, et al. 2013 (36)	9 weeks	238/210 (88%) Injured: 34	37.2 (11.2)	77/133	23.9 (3.4)	Short-distance: novice runners training for a 6.7 km event	Any self-reported MSC of lower extremity or back, causing a restriction of running for at least 1 week	Demographic and kinetic variables	Overall running-related injuries
Buist[1], et al. 2010 (37)	8 weeks	875/629 (72%) Injured: 163	43.7 (9.5)	208/421	24.9 (3.3)	Short-distance: novice and regular runners training for a 6.7 km event	MSC of lower extremity or back, causing a restriction of running for at least 1 day	Demographic variables and training characteristics	Overall running-related injuries

Author, year of publication	follow-up	Included/Analysed (%), Injured (N)	Age (yr) mean ± sd	Sex (m/f)	BMI (kg/m²) mean (sd)	Running type	Injury definition	Risk or protective factor(s)	Type of injury
Hesar, et al. 2009 (38)	10 weeks	131/131 (100%) Injured: 27	39.1 (10.3)	20/111	24.9*	Short-distance: start-to-run program of 5 km	All sports injuries that occurred during the program	Gait-related intrinsic risk factors	Overall running-related injuries
Malisoux, et al. 2015 (39)	9 months	754/517 (69%) Injured: 167	42.2 (9.9)	336/181	unclear	Short-distance: self-structured running program, mean 22km/week, with a frequency of 2 times/week	Any physical pain located at the lower limb or lower back region, sustained during or as a result of running practice and impeding planned running activity for at least 1 day	Running frequency and volume, BMI and previous injury	Overall running-related injuries and traumatic non-contact injuries
Nielsen[1], et al. 2014 (40)	1 year	933/873 (94%) Injured: 202	37.2 (10.3)	441/432	26.1 (4.2)	Short-distance: novice runners with a self-structured running program	MSC of lower extremity or back caused by running, which restricted the amount of running for at least 1 week	Increasing weekly running distance	Overall running-related injuries
Nielsen[2], et al. 2014 (41)	1 year	951/927 (97%) Injured: 252	37.1 (95%CI 36.5-37.8)	466/461	26.3 (95%CI 26.0-26.6)	Short-distance: novice runners with a self-structured running program	MSC of lower extremity or back caused by running, which restricted the amount of running for at least 1 week	Foot posture	Overall running-related injuries
Ramskov, et al. 2015 (42)	1 year	832/629 (76%) Injured: 24	36.6 (10.1)	321/308	26.1 (4.4)	Short-distance: novice runners with self-structured running program	MSC of lower extremity or back caused by running, resulting in a restriction of running for at least 1 week	Eccentric hip abduction strength	Patellofemoral pain
Thijs, et al. 2008 (43)	10 weeks	129/102 (79%) Injured: 17	37 (9.5)	13/89	25 (3)	Short-distance: start-to-run program of 5 km	Characteristic history and symptoms of PFP syndrome and exhibit 2 of the following criteria: pain on direct compression of the patella, tenderness of the posterior surface of the medial or lateral rim of	Gait-related intrinsic risk factors	Patellar Femoral Pain

Author, year of publication	follow-up	Included/Analysed (%), Injured (N)	Age (yr) mean ± sd	Sex (m/f)	BMI (kg/m²) mean (sd)	Running type	Injury definition	Risk or protective factor(s)	Type of injury
							the patella on palpation, pain with isometric quadriceps muscle contraction		
Thijs, et al. 2011 (44)	10 weeks	77/77 (100%) Injured: 16	38 (9)	0/77	24.6 (2.9)	Short-distance: 10 week start-to-run program	Runners who had to cease participation in the running program, because of patellofemoral dysfunction and had a characteristic history and symptoms of PFPS	Hip muscle weakness	Patellar Femoral Dysfunction Syndrome
van Ginckel, et al. 2009 (45)	10 weeks	129/129 (100%) Injured: 10	39 (No information)	10/46	Injured (N=10) 24.95 (4.12) Uninjured (N=53) 24.69 (3.89)	Short-distance: start-to-run program of 5 km	A musculoskeletal ailment that causes a restriction of running speed, distance, duration or frequency for at least 1 week	Intrinsic risk factors	Achilles tendinopathy
Napier, et al., 2018 (46)	15 weeks	74/65 (92%) Injured: 22	36.3 (8.4)	0/74	22.7 (2.5)	Short distance: 19km/week	The injury was deemed to be running-related, overuse, musculoskeletal (low back and lower extremities), and reported to be the cause of missing 3 training days within a 2-week window	Kinetic variables	Overall running-related injury
Taunton, et al. 2003 (47)	13 weeks	844/840 (100%) Injured: 249	Categorical N=141, <30 yr N=502, 31-49 yr N=111, 50-55 yr N=74, >56 yr	205/635	Categorical N=29, <19 N=556, 20-26 N=190, >26	Short-distance: training program of 10 km	If a runner experienced at least a grade 1 injury: pain only after exercise	Sociodemographic and training-related factors	Overall running-related injuries

BMI: Body Mass Index, *BMI calculated from height/weight, MSC: Musculo Skeletal Complaint, PFPS: patellofemoral painsyndrome, sd: standard deviation, yr: years, m: male, f: female.

Table 3: Description of participants, injury type and definition and risk factors in single factors studies in long distance runners

Author, year of publication	follow-up	Included/Analysed (%), Injured (N)	Age (yr) mean ± sd	Sex (m/f)	BMI (kg/m²) mean (sd)	Running type	Injury definition	Risk or protective factor(s)	Type of injury
Brund, et al. 2017 (48)	1 year	99/79 (80%) Injured: 25	39 (?)	79/0	23.9	Long-distance: 30 km/week	An absence of running for a minimum of 1 week due to MSC in lower extremity or back, caused by running	Medial or lateral ground pressure of the foot.	Achilles tendinopathy, Plantar fasciitis Medial tibial stress syndrome (APM-injuries)
Hespanhol Junior, et al. 2013 (49)	3 months	200/191 (96%) Injured: 84	42.8 (10.5)	141/50	24.4 (3.1)	Long-distance: recreational runners, mean 28km/week with a frequency of 3 times per week	Any pain of musculoskeletal origin, attributed to running by runners themselves and severe enough to prevent the runner from performing at least 1 training session	Previous RRI, speed training and interval training	Overall running-related injuries
Hespanhol Junior, et al. 2016 (50)	3 months	89/89 (100%) Injured: 24	44.2 (10.6)	68/21	24.2 (3.5)	Long-distance: 35 km/week	If runners missed at least 1 training session due to MSC	Lower limb alignments	Overall running-related injuries
Hirschmüller, et al. 2012 (51)	1 year	634/427 (67%) Injured: 29	43.2 (11)	285/142	23.0 (2)	Long-distance: 34.6km/week	Pain 2-6 cm proximal to the insertion and at least two of the following minor criteria: palpable thickening of the tendon, tenderness on bilateral pressure of the tendon, morning stiffness of the tendon, or pain at the beginning of activity	Previous Achilles disorders and neovascularization	Achilles tendon pain
Hotta, et al. 2015 (52)	6 months	101/84 (83%) Injured: 15	20 (1.1)	84/0	19.6 (4.8)	Long-distance: collegiate track and field middle or long-distance runners	MSC that 1) occurred as a result of participating in a practice or race in track and field, or 2) was sufficient severe to prevent participation for at least 4 weeks	Functional Movement Screening	Overall running-related injuries
Kelsey, et al. 2007 (53)	2 years	150/127 (85%) Injured: 18	22 (2.6)	0/127	21.2 (1.9)	Long-distance: minimum of 40km/week	A stress-fracture confirmed by x-ray, bone scan or magnetic resonance imaging	Previous stress fracture, bone mineral content, age and calcium intake	Stress fractures
Reinking, et al. 2007 (54)	1 season	88/67 (76%) Injured: 26	19.5 (Range 18-24 yr)	44/44	No information	Long-distance: mean of 64km/week	Unclear	Intrinsic and extrinsic risk factors	Overall running-related injuries
Messier, et al., 2018 (55)	Prospective cohort, 2 years	300/252 (84%), Injured: 199	36.3 (8.4)	0/74	22.7 (2.5)	Long-distance: 20 miles/week	The injury was deemed to be running-related, overuse, musculoskeletal (low back and lower extremities), and reported to be the cause of missing three training days within a two-week moving window	Kinetic variables	Overall running-related injury

BMI: Body Mass Index, MSC: Musculo Skeletal Complaint, sd: standard deviation, yr: years, m: male, f: female.

Table 4: Description of participants, injury type and definition and risk factors in risk model studies in short- and long distance runners

Author, year of publication	follow-up	Included/Analysed (%), Injured (N)	Age (yr) mean (sd)	Sex (m/f)	BMI (kg/m²) mean (sd)	Running type	Injury definition	Risk or protective factor(s)	Type of injury
van Middelkoop, et al. 2008 (19)	4 weeks	725/694 (96%) Injured: 195	44 (9.6)	694/0	23.5 (2.1)	Long-distance: marathon	MSC attributed to running, severe enough to cause a reduction in the distance, speed, duration or frequency of running	Sociodemographic and training-related factors	Overall running-related injuries
van Poppel, et al. 2016 (23)	5 weeks	864/614 (71%) Injured: 142	43.8 (11.2)	414/200	23.1 (2.5)	Long-distance: (half) marathon	Self-reported MSC that has to reduce running intensity or frequency, or need medical consultation	Training characteristics and sociodemographic variables	Overall running-related injuries
van Poppel, et al., 2018 (24)	5 weeks	3768/2763 (73%) Injured: 811	42.8 (11.2)	2270/1498	23.4 (2.5)	Mixed distances	Self-reported complaints of muscles, joints, tendons or bones in the lower extremity, due to running activities by which the running intensity or frequency was reduced, or medical consultation was needed	Training characteristics and sociodemographic variables	Overall running-related injury
Wen, et al. 1998 (56)	32 weeks	355/255 (71%) Injured: 90	41.8 (10.8)	107/148	M: 25.6* F: 23.8*	Long-distance: marathon training program	A running injury met the following criteria: having had 'injury or pain' to an anatomic part; having had to stop training, slow pace, stop interval or otherwise having had to modify training and a 'gradual' versus 'immediate' onset of injury or a self-reported diagnosis that is generally considered an overuse injury	Lower extremity alignment	Overall running-related injuries

BMI: Body Mass Index, MSC: Musculo Skeletal Complaint, sd: standard deviation, yr: years, m: male, f: female, *BMI calculated because authors only described height and weight.

Table 5: Grading assessment quality of evidence **(GRADE),** summary table of most important significant risk factors in two or more studies

Prognostic factor	Number of studies	Number of participants	Phase	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Effect size	Dose effect	Overall quality
Short distance runners											
Personal factors											
Age (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
Age (females)	3	2322	1	↓	↓	V	V	x	x	x	++
BMI (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
BMI (males)	3	2322	1	↓	↓	V	V	x	x	x	++
Sex	3	3580	1	V	↓	V	V	x	x	x	+++
Running experience (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
Previous sports participation (males)	2	1478	1	V	↓	V	↓	x	x	x	++
Foot morphology (generic)	2	1384	1	V	↓	V	↓	x	x	x	++
Training related factors											
Lower weekly volume (min)	2	2526	1	↓	V	V	V	x	x	x	+++
Distance (km)	2	1366	1	V	↓	V	↓	x	x	x	++
Health related factors											
Previous RRI (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
Previous injury not attributed to running	2	2705	1	V	V	V	V	x	x	x	++++
Long distance runners											
Health related factors											
Previous RRI	3	922	1	↓	V	V	↓	x	↑	x	+++

Generic includes both male and female runners. V=no serious limitations, ↓=serious limitations (x= not applicable). If only 1 study was found with significant results downgrading was done for inconsistency and imprecision. For overall quality of evidence: +very low; ++ low; +++ moderate; ++++ high.

Health related factors

Previous RRI. Four studies included previous RRIs as a potential risk factor[14,16,20,22]; three of these studies included both male and female recreational runners. Two studies (low RoB) found no association[16,22], while one study (low RoB) found a previous RRI is a risk factor for RRIs[20]. We found moderate quality evidence (downgraded for inconsistency) that previous RRIs is not a risk factor.

One study (low RoB) found that a previous RRI is associated with new RRIs in male runners (low quality evidence (single study, downgraded for inconsistency and imprecision))[14].

Musculoskeletal injury. Two studies (low RoB) found that a previous injury (musculoskeletal complaint) not attributed to running is a risk factor (high quality evidence) for new injuries RRIs in short-distance runners[16,22].

Long-distance runners

Personal factors

Age. Two studies included age as a potential risk factor; one study (high RoB) in a generic population did not present data[51]. One study (medium RoB) found higher age to be a protective factor for RRIs in female runners[53]. We found very low quality evidence (single study, downgraded for study limitations, inconsistency, indirectness and imprecision) that age is a protective factor in females.

BMI. Two studies assessed BMI as a potential risk factor but did not present data[51,53]. Three studies included weight as a potential risk factor[51,53,55]; of which one (high RoB) presented data and found no association[55]. We found very low quality evidence (single study, downgraded for study limitations, imprecision and inconsistency) that weight is not a risk factor for RRIs in a generic population. Two studies included length as a potential risk factor, but did not present data[51,53].

Training related factors

Training volume. Two studies included volume as a potential risk factor[53,54]. One study (1 medium RoB) found no statistically significant association in female runners[53] and 1 study (high RoB) presented no data[54]. We found very low quality evidence (single study, downgraded for study limitations, inconsistency and imprecision) that volume is not a risk factor for RRIs.

Health related factors;

Previous running injuries. The association between previous RRIs and new RRIs was assessed in four studies[49,51,53,54]. Three studies (1 medium RoB, 2 high RoB) found associations between previous injuries and new RRIs in a generic population[49,51,54], of which one study (high RoB) for Achilles tendinopathy specifically[51]. We found moderate quality evidence (downgraded for study limitations and indirectness, and upgraded for effect size) that a previous injury is a risk factor for new RRIs.

One study (medium RoB) found a previous injury to be a risk factor for stress fractures in female long-distance runners[53]. We found very low quality evidence (single study, downgraded for study limitations, indirectness, inconsistency and imprecision) that a previous RRI is a risk factors for RRIs in female long-distance runners.

Risk models

We found a total of 11 risk models in 4 studies in short- and long-distance runners; in 5 km, 10 km, half marathon and marathon runners[19,23,24,56]. One study found a risk model for RRIs in 5 km and 10-15 km runners[23]. One study found a risk model for RRIs in half marathon runners[24] and four studies found a risk model for RRIs in marathon runners[19,23,24,56]. One study found a risk model for foot- and shin injuries but no knee injury model was found[56]. One study also found a risk model for knee- and calf injuries[19]. All models found varied concerning the relevant predictors; and all but one had an area under the curve (AUC) of approximately 70% or higher. All models were graded as of low quality as these are all in the derivation stage. Three studies, which developed 8 risk models were applicable in regard to population, prediction outcome and analysis[23,24,56]. One study, which developed 3 models, had concerns about the applicability due to the fact that only male marathon runners were included[19].

There is no evidence that these models are predictive for RRIs.

The results for risk models in short- and long-distance runners are summarized in Table 6 and appendix H.

Discussion

No previous reviews addressed differences in risk factors between short- and long-distance recreational runners and used the GRADE approach to judge the overall quality of evidence. In this systematic review other risk factors were found in both short- and long-distance runners. We found a previous running related injury was the strongest risk factor with moderate quality evidence for an injury in long-distance runners. In a generic population previous injuries which were not attributed to running was the strongest risk factor with high quality evidence in short-distance runners. Higher Body Mass Index, higher age, sex (male) , having no previous running experience and running volume (<2 hours per week) were strong risk factors with moderate quality evidence for short-distance runners. Low quality evidence was found for risk models as predictor for running related injuries in short- and long-distance runners.

Table 6: Risk models

	Risk model, authors	Remained variables in model	Performance measures	Quality of the Evidence
Short distance	Running injuries versus no running injuries in 5 km runners (van Poppel (2016)	Previous injury (yes/no); OR 4.1 (95% CI; 2.2-7.6) Weekly distance; OR 0.95 (95% CI; 0.90-0.99) Age; OR 0.97 (95% CI; 0.95-0.99)	AUC (95% CI): 0.71 (0.64-0.79)	Low quality
	Running injuries versus no running injuries in 10-15km runners; van Poppel (2016)	Previous injury (yes/no); OR 3.8 (95% CI; 2.7-5.3) Weekly distance; OR 0.97 (95% CI; 0.95-0.99) BMI; OR 1.1 (95% CI; 1.0-1.2) Weekly training frequency; OR 1.3 (95% CI; 0.99-1.70 Age; OR 0.98 (95% CI; 0.97-0.99)	AUC (95% CI): 0.70 (0.66-0.73)	Low quality
Long distance	Injuries versus no injuries in marathon runners; Wen (1998)	High experience; OR 1.881 (95% CI; 1.159-3.053) Previous injuries; OR 2.018 (95% CI; 1.268-3.212)	Goodness of fit 1.833	Low quality
	Shin splints injuries versus no shin splints injuries in marathon runners; Wen (1998)	Interval; OR 14.886 (0.504-147.327 Old shin splints injuries; OR 7.235 (2.399-21.815))	Goodness of fit 0.722	Low quality
	Foot injuries versus no foot injuries in marathon runners; Wen (1998)	High experience; OR 1.088 (95% CI; 1.027-1.152) Weight; OR 0.941 (0.892-0.992)	Goodness of fit 0.464	Low quality
	Injuries versus no injuries in male marathon runners; Middelkoop (2008)	Race participation >7 times per year in comparison with 3-6 per year (reference); OR 1.66 (95% CI; 1.08-2.56) Injury previous 12 months; OR 2.62 (95% CI; 1.82-3.78) Daily smoking; OR 0.23 (95% CI; 0.05—1.01)	AUC: 0.65	Low quality
	Knee injuries versus no knee injuries in male marathon runners; Middelkoop (2008)	Interval training (always); OR 0.49 (95% CI; 0.26-0.93) Injury previous 12 months; OR 3.67 (95% CI; 0.26-0.93) Running experience; 0-4 years; OR 1.43 (95% CI; 0.63-3.26) 15+ years; OR 2.56 (95% CI; 1.22-5.34)	AUC: 0.69	Low quality
	Calf injuries versus no calf injuries in male marathon runners; Middelkoop (2008)	High education level; OR 0.60 (95% CI; 0.33-1.10) Training distance (km); 0-40 km; OR 0.36 (95% CI; 0.17-0.78) 60+ km; OR 0.57 (95% CI; 0.27-1.19) Athletics association; OR 0.58 (95% CI; 0.31-1.09) Incident injury other location; OR 2.57 (95% CI; 1.42-4.67)	AUC: 0.72	Low quality
	Running injuries versus no running injuries in marathon runners; van Poppel (2016)	Interval training (always vs sometimes); OR 0.67 (95% CI; 0.33-0.81) Running experience; 0-4 years; OR 1.87 (95% CI; 1.13-3.11) 5-10 years; OR 1.14 (95% CI; 0.64-2.01)	Nagelkerke R^2: 0.045	Low quality
	Running injuries versus no running injuries in half marathon runners; van Poppel (2018)	Previous injury (yes/no); OR 3.3 (95% CI; 2.3-4.8) Weekly distance; OR 0.98 (95% CI; 0.97-1.0)	AUC (95% CI): 0.67 (0.62-0.71)	Low quality
	Running injuries versus no running injuries in marathon runners; van Poppel (2018)	Previous iniury (yes/no); OR 4.3 (95% CI; 2.9-6.1) Weekly distance; OR 0.98 (95% CI; 0.97-0.99)	AUC (95% CI): 0.68 (0.64-0.72)	Low quality

Since 2000, five systematic reviews (SRs) assessing risk factors for running injuries of the lower extremity have been published[5,10,12,16,57]. None of these studies only included prospective designs with multivariable analysis and aimed on differences in short- and long-distance runners.

Differences in associations between injuries and risk factors may be explained by differences in selection criteria, study designs, risk of bias tool and data synthesis methods used. Inclusion criteria differed between the SRs leading to differences in the included studies. For instance, one review only included studies with overall lower extremity injuries and not with specific injuries[57]. The other four SRs included several designs, such as randomized controlled trials, retrospective cohort and cross-sectional studies. Different methods were used for quality assessment of the included articles. Our systematic review used the QUIPS as assessment tool to assess risk of bias, the other four used different quality lists to assess the risk of bias of the studies. As a consequence, differences in methodological quality of included studies were found in the different SRs. For example, the study of Hirschmüller et al. (2012) was classified as high quality in the SR of van der Worp et al. (2015), but in this review as having low quality (high RoB), which might result in different conclusions. In contrast to our study, none of the SRs used the GRADE approach to assess the quality of the evidence.

Previous reviews found a previous injury to be a risk factor[5,10,12,16,57]. In this study also a previous RRI was found to be the strongest risk factor in long-distance runners but the definition of a previous injury differed in the included studies ranging from missing sports practice with unclear timeframe[54] to injuries due to running in 12 months preceding the event[23]. It remains unclear whether a higher injury risk is related to an incomplete healing of the previous injury, changed biomechanics due to the previous injury or other reasons. Although there is no uniform definition of previous RRIs and RRIs, many articles confirmed the association, it may be assumed that a previous injury increases the risk of new injuries. It is unclear why this association was not found in short-distance runners. In our review two (out of 4) studies found a previous RRI to be a risk factor. A possible explanation is that most studies in short-distance runners included novice runners. Some novice runners just started running and therefore could not have had previous RRIs. Previous injuries not attributed to running was the strongest risk factor. A possible mechanical explanation is that runners who already have had musculoskeletal complaints without running are more likely to get injured when they do run, because biomechanical loading capacity is lower[16].

We found moderate quality evidence that no previous running experience is a risk factor for running injuries in short-distance runners. Also, limited evidence for running experience as risk factor was found in three other SRs[5,10,12]. The influence of running experience differs in different running distance populations. An explanation why short- distance runners without experience possibly have a higher risk of injury, is that novice runners possibly build up their training too quickly, resulting in a lack of time for tissue to adapt to training loads. In line with these studies we found moderate quality evidence for a lower running volume as a risk factor in short-distance runners[15,39]. Although, this conclusion has to been interpreted carefully while running more than 60 min/per week is protective. It does not necessarily mean running less than 60 min/week is a risk factor. A relationship with a higher age can be suggested. More experienced runners are often older. Although inconsistent evidence for age was found in this review, it is suggested that older age runners have a higher risk of osteoarthritis which could explain that more experienced runners are at higher risk of injury than less experienced runners[58].

We found low quality evidence having a higher BMI is a risk factor for RRIs[14,16,37]. Another SR investigated this association, but did not found BMI to have a significant effect on running injuries[12]. This difference in results could be explained by different types of injuries. Many studies examined BMI as a risk factor for overall injuries. However, there is a possibility that a lower or higher BMI increases the risk of different specific injuries. For instance, a lower BMI is associated with a lower bone mineral density and thereby could increase the risk of stress fractures. Increased BMI was significantly associated with development of a medial tibial stress syndrome possibly due to the heavier impact loads that are likely to be associated with an increased BMI[59-62].

Strengths and limitations

Only prospective cohort studies were included as this is considered as the best study design to determine risk factors[29,63]. A second strength is that this systematic review mainly used results from multivariable analyses and only risk factors which were adjusted for confounders[27]. Moreover, this is the first systematic review in RRIs that used the GRADE approach for data synthesis.

In only a few studies[22,45,51-53] it was unclear which confounders were used. Moreover, in the studies who adjusted the analyses for confounders the type of confounders often differed between the studies. In addition, different methods of reporting the risk were used like, odds, hazard or relative risk ratios which makes it sometimes difficult to compare risk or protective factors. For instance, higher BMI was often not presented with clear cut-off points. Furthermore, it might be better to define injury specific risk factors in a systematic review, as several risk factors could have different influences on different injuries[12,64]. However, at this moment, too few studies are available to summarize injury specific risk factors and the large diversity of injury definitions, populations and research methods in studies makes it difficult to make comparisons across studies.

Although five electronic databases were searched and selection bias was minimized using an adequate selection procedure and an inclusion form, it is possible that other articles eligible for inclusion were missed. Also, unpublished studies could have been missed[31]. Differences found in risk factors between short- and long-distance runners could be explained by the fact that some factors were probably examined in short-distance studies only and not in long-distance studies or vice-versa.

In this study, running distance was dichotomized to short-distance or long-distance runners. However, the population is quite heterogeneous in many studies, especially regarding the training pattern. The studies included in this review can include both short-distance or long-distance runners (and the proportion might be balanced). Some risk factors might actually not be specific to one or the other category, as stated in this study. Also, the criteria used to classify runners in short- and long-distance runners is arguable. In 2 out of 29 studies, running distance was around the cut-off point and these studies were hard to classify[39,46]. Finally, 2/3 of the studies in this review included short-distance runners and many studies on short-distance runners specifically focused on novice runners. The risk factors identified in the present work for short-distance runners could be more specific to novice runners rather than being related to the running distance profile. Also, this could be an explanation for the observed “differences” in risk factors between short- and long-distance runners. None of the included papers directly compared the risk factors for RRIs between the two groups of interest although this kind of study design would optimally meet our research question. Therefore, our results have to be interpreted with caution.

To improve insight into differences in risk factors between short- and long-distance runners, more high-quality prognostic studies are needed which compare the two groups or further prognostic studies should include short- and long-distance runners and present these results separately not only in regard to distance but also injury location. Also, a uniform definition of (previous) RRIs should be used, for example as recommended by a Delphi-study)[65].

Conclusion

Evidence for risk factors for RRI is limited. Running injuries seem to have a multifactorial origin. There is a need for high quality studies of risk factors for RRIs before strong conclusions can be drawn about the relevance of specific risk factors. Furthermore, consensus must be achieved about the definition of running injuries, and large cohort studies are needed to investigate different types (personal, training related, health related) of risk factors with emphasis on differences between short- and long-distance runners. In this study previous injuries not attributed to running, higher Body Mass Index, higher age, sex (male), having no previous running experience and running volume are important risk factors for RRIs in short-distance runners while having previous running related injuries is an important risk factor for long-distance runners.

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Appendices

Appendix A: Search strategy databases

((“Running/injuries”[Mesh] OR “Track and Field/injuries”[Mesh] OR “Running injuries”[tiab]) OR ((“Running”[Mesh] OR “Track and Field”[Mesh] OR runn*[tiab] OR jogg*[tiab] OR marathon*[tiab]) AND (“Leg Injuries”[Mesh] OR “Hip Injuries”[Mesh] OR “Knee Injuries”[Mesh] OR “Ankle Injuries”[Mesh] OR “Foot Injuries”[Mesh:NoExp] OR “Back Injuries”[Mesh] OR “Athletic Injuries”[Mesh] OR “Fractures, Stress”[Mesh] OR “Soft Tissue Injuries”[Mesh] OR “Medial Tibial Stress Syndrome”[Mesh] OR “Sprains and Strains”[Mesh:NoExp] OR “Iliotibial Band Syndrome”[Mesh] OR “Tendon Injuries”[Mesh] OR “Tendinopathy”[Mesh:NoExp] OR “Fasciitis, Plantar”[Mesh] OR “Patellofemoral Pain Syndrome”[Mesh] OR “Bursitis”[Mesh:NoExp] OR “tendinopathy”[tiab] OR “tendinitis”[tiab] OR “shin splints”[tiab] OR “plantar fasciitis”[tiab] OR “Bursitis”[tiab] OR injur*[tiab] OR “patellofemoral pain”[tiab]))) AND (“Risk Factors”[Mesh] OR “determinant”[tiab] OR “determinants”[tiab] OR “risk”[tiab] OR “risks”[tiab] OR “etiology”[tiab] OR “Risk”[Mesh:NoExp] OR “etiology”[sh:NoExp] OR Etiology/Narrow[filter]) AND (“Cohort Studies”[Mesh] OR “Cohort Study”[tiab] OR “cohort”[tiab] OR “cohorts”[tiab] OR “longitudinal”[tiab] OR “follow-up”[tiab] OR “followup”[tiab] OR “prospective study”[tiab])

Pubmed	Search terms	Hits (n)	Relevant (n)
#1	See above	637	45

Cochrane	Search terms	Hits (n)	Relevant (n)
#1	"running injuries":ti,ab,kw	17	-
#2	MeSH descriptor: [Athletic Injuries] explode all trees	627	-
#3	MeSH descriptor: [Wounds and Injuries] explode all trees	19295	-
#4	MeSH descriptor: [Sprains and Strains] this term only	332	-
#5	MeSH descriptor: [Iliotibial Band Syndrome] explode all trees	4	-
#6	MeSH descriptor: [Medial Tibial Stress Syndrome] this term only	5	-
#7	MeSH descriptor: [Tendon Injuries] this term only	248	-
#8	MeSH descriptor: [Tendinopathy] this term only	351	-
#9	MeSH descriptor: [Soft Tissue Injuries] this term only	90	-
#10	MeSH descriptor: [Patellofemoral Pain Syndrome] explode all trees	105	-
#11	MeSH descriptor: [Fractures, Stress] this term only	46	-
#12	MeSH descriptor: [Foot Diseases] explode all trees	762	-
#13	"tendinopathies":ti,ab,kw	58	-
#14	"tendinopathies":ti,ab,kw	517	-
#15	"tendinitis":ti,ab,kw	471	-
#16	"shin splints":ti,ab,kw	9	-
#17	"plantar fasciitis":ti,ab,kw	274	-
#18	injur*:ti,ab,kw	35010	-
#19	"patello-femoral pain":ti,ab,kw	6	-
#20	#2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19	44838	-
#21	MeSH descriptor: [Running] explode all trees	1635	-
#22	MeSH descriptor: [Track and Field] explode all trees	46	-
#23	"jogging":ti,ab,kw	293	-
#24	"jogger":ti,ab,kw	17	-
#25	runner:ti,ab,kw	794	-
#26	"marathon":ti,ab,kw	185	-
#27	"marathoner":ti,ab,kw	1	-
#28	#21 or #22 or #23 or #24 or #25 or #26 or #27	2202	-
#29	#20 and #28	235	-
#30	#1 or #29	238	-
#31	MeSH descriptor: [Risk] explode all trees	38064	-
#32	MeSH descriptor: [Risk Factors] explode all trees	24795	-
#33	risk:ti,ab,kw	150532	-
#34	determinant:ti,ab,kw	5444	-
#35	etiology:ti,ab,kw	14736	-
#36	#31 or #32 or #33 or #34 or #35	168539	-
#37	#30 and #36	80	2

CINAHL	Search terms	Hits (n)	Relevant (n)
S1	(MH "Running Injuries+")	291	-
S2	TI ("Running Injuries+")	62	-
S3	AB ("Running Injuries")	91	-
S4	S1 OR S2 OR S3	396	-
S5	(MH "Wounds and Injuries+")	163422	-
S6	TI injury	38117	-
S7	AB injury	79395	-
S8	AB injuries	29395	-
S9	TI injuries	13733	-
S10	(MH "Athletic Injuries+")	14210	-
S11	(MH "Soft Tissue Injuries")	1127	-
S12	(MH "Medial Tibial Stress Syndrome")	159	-
S13	(MH "Sprains and Strains+")	6277	-
S14	(MH "Iliotibial Band Friction Syndrome")	135	-
S15	TI tendinopathy	733	-
S16	AB tendinopathy	835	-
S17	AB tendinopathies	835	-
S18	TI tendinopathies	44	-
S19	TI tendinitis	227	-
S20	AB tendinitis	366	-
S21	AB shin splints	37	-
S22	TI shin splints	50	-
S23	TI fasciitis	918	-
S24	AB fasciitis	761	-
S25	AB bursitis	245	-
S26	TI bursitis	163	-
S27	TI patellofemoral pain	687	-
S28	AB patellofemoral pain	656	-
S29	S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28	207079	-
S30	(MH "Running+")	7298	-
S31	TI ("Running")	3001	-
S32	AB ("Running")	6015	-
S33	AB ("marathon")	547	-
S34	TI ("marathon")	680	-
S35	TI ("runners")	1012	-
S36	AB ("runners")	1645	-
S37	AB ("joggers")	19	-
S38	TI ("joggers")	17	-
S39	TI ("jogging")	86	-
S40	AB ("jogging")	0	-
S41	S30 OR S31 OR S32 OR S33 OR S34 OR S35 OR S36 OR S37 OR S38 OR S39 OR S40	12720	-
S42	S29 AND S41	2295	-
S43	S4 OR S42	2375	-
S44	TI risk	95031	-
S45	AB risk	258122	-
S46	(MH "Risk Factors+")	88411	-
S47	TI determinant	618	-
S48	AB determinant	15893	-
S49	AB determinants	15893	-
S50	AB determinants	15893	-
S51	TI determinants	5484	-
S52	TI risk	95031	-
S53	AB risk	258122	-
S54	AB etiology	16602	-
S55	TI etiology	1713	-
S56	(MH "Risk Assessment")	42844	-
S57	S44 OR S45 OR S46 OR S47 OR S48 OR S49 OR S50 OR S51 OR S52 OR S53 OR S54 OR S55 OR S56	387920	-
S58	S43 AND S57	612	-
S59	(MH "Prospective Studies+")	201132	-
S60	("cohort Studies")	3214	-
S61	("longitudinal Studies")	2548	-
S62	longitudinal	35027	-
S63	follow-up	99815	-
S64	follow up	99896	-
S65	Follow up	3545	-
S66	cohort	79884	-
S67	S59 OR S60 OR S61 OR S62 OR S63 OR S64 OR S65 OR S66	309028	-
S68	S58 AND S67	146	10

SPORTDiscus	Search terms	Hits (n)	Relevant (n)
S1	DE "RUNNING injuries" OR DE "MORTON'S foot" OR DE "SHIN splints"	2569	-
S2	TI "RUNNING injuries"	203	-
S3	AB "RUNNING injuries"	302	-
S4	S1 OR S2 OR S3	2718	-
S5	DE "WOUNDS & injuries -- Risk factors"	150	-
S6	TI injuries	32542	-
S7	AB injuries	67560	-
S8	AB injury	67560	-
S9	TI injury	32542	-
S10	DE "SPORTS injuries"	7703	-
S11	DE "SOFT tissue injuries"	543	-
S12	DE "SHIN splints"	424	-
S13	TI medial tibial stress syndrome	71	-
S14	AB medial tibial stress syndrome	130	-
S15	DE "ILIOTIBIAL band syndrome"	122	-
S16	TI sprains	960	-
S17	AB sprains	2291	-
S18	AB strains	7049	-
S19	TI strains	1851	-
S20	TI tendinopathy	950	-
S21	AB tendinopathy	1347	-
S22	AB stress fractures	1491	-
S23	TI stress fractures	1080	-
S24	TI tendinopathies	950	-
S25	AB tendinopathies	1347	-
S26	AB tendinitis	806	-
S27	TI tendinitis	405	-
S28	TI fasciitis	348	-
S29	AB fasciitis	566	-
S30	AB bursitis	291	-
S31	TI bursitis	103	-
S32	S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31	94217	-
S33	DE "RUNNING"	22155	-
S34	DE "JOGGING"	1513	-
S35	DE "JOGGING injuries"	5	-
S36	DE "MARATHON running" OR DE "MARATHONS (Sports)"	17012	-
S37	TI "MARATHON"	5027	-
S38	AB "MARATHON"	13932	-
S39	AB "runners"	16649	-
S40	TI "runners"	5172	-
S41	TI "running"	13931	-
S42	AB "running"	39143	-
S43	AB "jogging"	1309	-

S44	TI "jogging"	674	-
S45	S33 OR S34 OR S36 OR S37 OR S38 OR S39 OR S40 OR S41 OR S42 OR S43 OR S44	83264	-
S46	S32 AND S45	5787	-
S48	S46 OR S47	2722	-
S49	S5 AND S45	9	-
S50	DE "DISEASES -- Risk factors"	894	-
S51	TI Risk factors	3504	-
S52	AB Risk factors	14549	-
S53	AB determinant	6013	-
S54	TI determinant	2365	-
S55	TI etiology	521	-
S56	AB etiology	3640	-
S58	TI risk	63538	-
S59	S50 OR S51 OR S52 OR S53 OR S54 OR S55 OR S56 OR S57 OR S58	78419	-
S60	S48 AND S59	1011	-
S61	S49 OR S60	1013	-
S62	cohort study	6915	-
S64	longitudinal studies	6915	-
S65	longitudinal research	514	-
S66	cohort	13187	-
S67	follow-up	23328	-
S68	followup	594	-
S69	longitudinal research	514	-
S70	S62 OR S63 OR S64 OR S65 OR S66 OR S67 OR S68 OR S69	38289	-
S71	S61 AND S70	118	9

PsychINFO	Search terms	Hits (n)	Relevant (n)
S1	DE "Running"	2316	-
S2	TI "Running"	2108	-
S3	AB "Running"	13450	-
S4	AB "Runners"	876	-
S5	TI "Runners"	308	-
S6	TI "marathon"	343	-
S7	AB "marathon"	546	-
S8	AB "jogging"	251	-
S9	TI "jogging"	48	-
S10	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9	15466	-
S11	DE "Injuries"	11034	-
S12	TI "Injuries"	3105	-
S13	AB "Injuries"	16437	-
S14	AB "Injury"	59191	-
S15	TI "Injury"	25117	-
S16	TI tendinopathy	19	-
S17	AB tendinopathy	37	-
S18	AB tendinopathies	37	-
S19	TI tendinopathies	19	-
S20	TI tendinitis	12	-
S21	AB tendinitis	31	-
S22	AB shin splints	1	-
S23	TI shin splints	0	-
S24	TI fasciitis	16	-
S25	TI fasciitis	16	-
S26	AB fasciitis	26	-
S27	AB bursitis	27	-
S28	TI bursitis	4	-
S29	TI patellofemoral pain	41	-
S30	AB patellofemoral pain	51	-
S31	AB sprain	157	-
S32	TI sprain	29	-
S33	TI tibial stress syndrome	1	-
S34	AB tibial stress syndrome	2	-
S35	AB band friction syndrome	0	-
S36	AB soft tissue injury	94	-
S37	TI soft tissue injury	11	-
S38	TI "musculoskeletal pain"	434	-
S39	AB "musculoskeletal pain"	1142	-
S40	DE "Musculoskeletal System" OR DE "Bones" OR DE "Joints (Anatomy)" OR DE "Muscles" OR DE "Tendons"	13548	-
S41	S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35 OR S36 OR S37 OR S38 OR S39 OR S40	86032	-
S42	DE "Risk Factors"	114720	-
S43	TI "Risk"	67825	-
S44	AB "Risk"	281724	-
S45	DE "Etiology"	30560	-
S46	TI "Etiology"	2720	-
S47	AB "Etiology"	27846	-
S48	AB "determinant"	10551	-
S49	TI "determinant"	1483	-
S50	TI "determinants"	11934	-
S51	AB "determinants"	17504	-
S52	S42 OR S43 OR S44 OR S45 OR S46 OR S47 OR S48 OR S49 OR S50 OR S51	401223	-
S53	DE "Prospective Studies"	28878	-
S54	DE "Longitudinal Studies"	45110	-
S55	DE "Followup Studies"	12356	-
S56	TI "cohort Studies"	203	-
S57	AB "cohort Studies"	1628	-
S58	AB "cohort Study"	12289	-
S59	TI "cohort Study"	4008	-
S60	TI "longitudinal Study"	9661	-
S61	AB "longitudinal Study"	25597	-
S62	S53 OR S54 OR S55 OR S56 OR S57 OR S58 OR S59 OR S60 OR S61	112860	-
S63	S10 AND S41 AND S52 AND S62	4	0

Appendix B: Inclusion/exclusion criteria

Inclusion

a) assessed the association between individual risk factors and an RRI or developed (or validated) a risk model using multivariable logistic regression analysis for RRI;
b) population consisted short- or long-distance runners above 16 years old ((short-distance (mean running distance of ≤20km/week and ≤10km/session) or long-distance (mean running distance of >20km/week and >10km/session));
c) running distances were clearly described and the results were presented separately for the different running distances (if applicable, when more than one running distance was included in the study);
d) the design was a prospective cohort study, with a follow-up period of at least 4 weeks;
e) definition of a RRI was clearly described.

Exclusion criteria were: elite, professional or ultra-runners (>42,195km), triathletes, soccer or rugby athletes, soldiers, and a population with a total knee or hip prosthesis. Studies that assessed risk factors with an injured population at baseline, were also excluded.

Appendix C: Inclusion form

Name of rater:

REFERENCE

Author(s):

Title:

Journal (year, volume /issue, page(s):

Population in study; Runners with minimal age of 16 years and maximal running distance of 42.195 km (marathon). No treadmill runners, military runners, runners with diseases or elite runners.	
Correct population of runners:	Yes / No*
Running distances are clearly described and studies can be classified as short- or long-distance.	
Correct description of running distances:	Yes / No*
Published prospective cohort studies with minimal follow up period of 1 month were included.	
Correct study type:	Yes / No*
Outcome; Primary aim of study are risk factors.	
Risk factors are primary aim:	Yes / No*
Outcome; risk factors for RRI were described in terms of ODDS/relative risk/cumulative risk (logistic regression).	
Correct description of risk factors:	Yes / No*
Inclusion:	Yes / No*

Appendix D: Risk factors in more than one study in short- and long-distance runners

Risk factor	Short distance									Long distance								
	Female			Male			General			Female			Male			General		
	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+
Personal factors																		
Age	47	14,37				37	16	20, 22										
BMI	37			14	37	47	16	20, 22										
Sex							37	16,22			54			54			55	
Running experience	37			37			16	20,22										
Previous/other sports activity	37			14	37			16,20,22										
Behaviour					14		22											
Foot morphology			14					20	41									
Training related factors																		
Lower frequency	47						39	15										
Lower volume (min)							39,15											
Distance (km)							20	40										
Type of terrain		47			47			20										
Running shoe age	47					47		16, 20										
Intrinsic gait-related factors	38						45											
Health related factors																		
Previous RRI				14			20	16,22		53						49,51,54		
Previous injury not running related							16,20											

Reference numbers are according the reference list. - = risk factor; + = protective factor; 0 = no significant association. Studies are subdivided in generic population (General), females and males.

Appendix E: risk factors in short distance runners

	Potential prognostic factor	Ref	Estimated effect	GRADE
	Personal factors			
Age	Higher age	16	**HR (95%CI): 1.02 (1.00-1.04)**	+++
	Higher Age	20	HR (95%CI): 0.98 (0.96-1.00)	
	Age 18-30 years versus 30-45 years (ref)	22	cIRD (95%CI): -1.6% (-12.3%-9.2%)	
	Age 45-65 years versus 30-45 years (ref)	22	cIRD (95%CI): -14.7% (-2.1%-31.5%)	
	Increasing age by 10 years in males	**37**	**HR (95%CI): 0.63 (0.48-0.82)**	++
	Increasing age by 10 years in females	14	HR (95%CI) : 0.84 (0.62-1.13)	++
	Increasing age by 10 years in females	37	HR (95%CI): 0.82 (0.66-1.02)	
	Age >50 years in females	47	**RR (95%CI): 1.919 (1.107-3.328)**	
BMI	Higher BMI	16	**HR (95%CI): 1.04 (1.00-1.07)**	+++
	Higher BMI	20	HR (95%CI): 1.05 (0.96-1.14)	
	Higher BMI <20 kg/m2 versus normal (20-25 kg/m2) BMI	22	cIRD (95%CI): -14.1% (-31.6%-3.5%)	
	Higher BMI 25-30 kg/m2 versus normal (20-25 kg/m2) BMI	22	cIRD (95%CI): 2.7% (-10.2%-15.7%)	
	Higher BMI >30 kg/m2 versus normal (20-25 kg/m2) BMI	22	cIRD (95%CI): 10.3% (-3.7%-24.3%)	
	Higher BMI males	14	**HR (95%CI): 1.14 (1.05-1.25)**	++
	Higher BMI males	37	HR (95%CI): 1.02 (0.94-1.11)	
	BMI 26>higher in males	47	**RR (95%CI): 0.41 (0.21-0.78)**	
	Higher BMI females	37	**HR (95%CI): 1.06 (1.01-1.13)**	++
Sex	Males (female ref)	16	HR (95%CI): 1.00 (0.66-1.53)	+++
	Males (female ref)	22	cIRD (95%CI): -4.4% (-15.2%-6.4%)	
	Males (female ref)	37	**HR (95%CI): 1.42 (1.02-1.99)**	
Running experience	Not having previous running experience	16	**HR (95%CI): 2.38 (1.24-4.57)**	+++
	Running experience 3-12 months versus 3< months	20	HR (95%CI): 1.44 (0.54-3.83)	
	Running experience >12 months versus 3< months	20	HR (95%CI): 0.98 (0.38-2.51)	
	Not having previous running experience	22	cIRD (95%CI): 6.0% (-5.4%-17.3%)	
	Not having previous running experience (male)	37	**HR (95%CI): 2.61 (1.23-5.53)**	++
	Not having previous running experience (female)	37	**HR (95%CI): 2.14 (1.24-2.70)**	++
Previous sports activity	Being previously active without axial load versus axial loading	16	HR (95%CI) : 1.19 (0.77-1.86)	++++
	Being not previously active versus axial loading (ref)	16	HR (95%CI): 1.18 (0.80-1.74)	
	Other sports with axial loading versus no sports (ref)	20	HR (95%CI): 0.70 (0.42-1.15)	
	Other sports without axial loading versus no sports (ref)	20	HR (95%CI): 0.64 (0.24-1.69)	
	Other sports with axial loading versus no sports (ref)	22	cIRD (95%CI): -0.7% (-14.3%-12.8%)	
	Other sports without axial loading versus no sports (ref)	22	cIRD (95%CI): -2.4% (-18.9%-14.2%)	
	Other sports (males) without axial load versus axial loading (ref)	14	**HR (95%CI): 2.05 (1.03-4.11)**	++
	Being not previously active (males) versus axial loading (ref)	14	HR (95%CI): 1.23 (0.54-2.78)	
	Being previously active (males) with non-axial load (males) versus axial loading (ref)	37	HR (95%CI): 0.88 (0.41-1.93)	
	Being not previously active (males) versus axial loading (ref)	37	HR (95%CI): 1.08 (0.57-2.04)	
	Being previously active with non-axial load (females) versus axial loading (ref)	37	**HR (95%CI): 1.85 (1.07-3.21)**	++
	Being not previously active (females) versus axial loading (ref)	37	HR (95%CI): 1.53 (0.88-2.66)	
Behaviour	Competitive behaviour; TASRI type A (ref type B)	22	**cIRD (95%CI): -11.9% (-23.3% - -0.5%)**	++

	Behaviour type A/B in males, sumscore Jenkins (male)	14	HR (95%CI): 1.02 (0.99-1.04)	++
Foot morphology	Navicular drop	20	HR (95%CI): 1.00 (0.92-1.09)	++
	Pronated compared to neutral feet (ref)		**cIRD (95%CI): 1000km (95%CI):**	
	Highly supinated compared to neutral feet (ref)	41	**-0.37 (-0.03 - -0.70)**	
	Supinated compared to neutral feet (ref)	41	0.24 (-0.44 -0.93)	
	Highly pronated compared to neutral feet (ref)	41	0.03 (-0.25 - 0.31)	
		41	2.25 (-0.35 – 4.85)	
	Normal navicular drop compared to high navicular drop (females)	14	**HR (95%CI): 0.87 (0.77-0.98)**	++
Other	Extension MTP 1	20	HR (95%CI): 1.00 (0.98-1.02)	+
	Training related factors			
Running frequency	Weekly frequency <2 sessions versus 2 sessions (ref)	15	HR (95%CI): 0.85 (0.67-1.08)	+++
	Weekly frequency 3 sessions versus 2 sessions (ref)	15	HR (95%CI): 1.18 (0.98-1.42)	
	Weekly frequency 3> sessions versus 2 sessions (ref)	15	HR (95%CI): 0.89 (0.47-1.67)	
	Weekly frequency <2 sessions	39	RR (95%CI): 2.44 (0.48-4.39)	
	Weekly frequency, 1 day per week (female)	47	**RR (95%CI): 3.65 (1.08-12.30)**	+
Running volume	Weekly volume ≥60 minutes	15	**1) HR (95%CI): 0.41 (0.20-0.86)**	+++
	Weekly volume <2 hours	39	**2) RR (95%CI): 4.69 (1.42-7.95)**	
Running distance	Weekly running distance; 10-20 km/week versus <10 km (ref)	20	HR (95%CI): 0.90 (0.48-1.67)	++
	Weekly running distance; 21-30km/week versus <10 km (ref)	20	HR (95%CI): 1.92 (0.91-4.07)	
	Weekly running distance; > 30km/week versus <10 km (ref)	20	**HR (95%CI): 3.28 (1.23-8.75)**	
	Weekly progression in distance of 10-30% versus <10% (ref)	40	HR (95%CI): 0.99 (0.55-1.82)	
	Weekly progression in distance of >30% versus <10% (ref)	40	HR (95%CI): 1.17 (0.84-1.63)	
Type of terrain	Hard terrain versus soft terrain (ref)	20	HR (95%CI): 0.83 (0.24-1.69)	++
	Combination terrain versus soft terrain (ref)	20	HR (95%CI): 0.64 (0.19-2.17)	
Running shoe	Running shoe age; 3-12 months old versus 3<months (ref)	16	HR (95%CI): 1.24 (0.80-1.90)	++++
	Running shoe age; >12 months old versus 3<months (ref)	16	HR (95%CI): 1.03 (0.64-1.67)	
	Running shoe age; 3-12 months old versus 3<months (ref)	20	HR (95%CI): 1.36 (0.69-2.69)	
	Running shoe age; >12 months old versus 3<months (ref)	20	HR (95%CI): 1.85 (0.89-3.83)	
	Running shoe age; 4-6 months old (male)	47	**RR (95%CI): 0.35 (0.15-0.83)**	+
	Running shoe age; 4-6 months old in (female)	47	**RR (95%CI): 1.73 (1.1-2.98)**	+
Hip	hip abduction strength	42	**CC risk difference % (95%CI):**	+
			25km: - 0.6 (-1.3-0.1)	
			50km: - 0.9 (-1.7 - -0.1)	
	Hip internal rotation in females	14	HR (95%CI): 0.99 (0.97-1.01)	+
	Hip-waste ratio	16	HR (95%CI): 1.20 (0.13-11.10)	+
Intrinsic gait-related factors	Higher total anterior posterior displacement in the COF	45	**OR (95%CI): 0.919 (0.86-0.98)**	+
	Higher total anterior posterior displacement in the COF	38	**OR (95%CI): 1.75 (1.09-2.80)**	+
	Medial directed underneath the forefoot at 'forefoot flat'	45	**OR (95%CI): 0.00 (0.00-0.16)**	+
	Force distribution and COF displacement	38	**OR (95%CI): 0.51 (0.27-0.95)**	+
	Faster mediolateral and anteroposterior velocity displacement of COF in forefoot flat (female)		OR (95%CI): 0.65 (0.42-1.01)	
	Medial directed force displacement in forefoot contact phase (FFCP), forefoot flat phase (FFP) and heel off (HO). Lateral directed force displacement in forefoot push off phase (female)	38	**FFCP: OR (95%CI): 0.40 (0.22-0.73)** **FFP: OR (95%CI): 0.59 (0.36-0.96)** **HO: OR (95%CI): 0.74 (0.61-0.90)**	

			FFPOP: OR (95%CI): 1.67 (1.08-2.57)	
			FF: OR (95%CI): 0.63 (0.40-0.99)	
	Medial directed force distribution at forefoot flat (FF) and first metatarsal contact (FMC) (female)	38	**FMC: OR (95%CI): 0.64 (0.42-0.97)**	
	Higher peak force metatarsal 5 (female)	38	**OR (95%CI): 1.68 (1.09-2.60)**	
	Fmax medial heel	43		
Vertical load or impuls	Average vertical loading rate (BW/s) in tertiles	46		+
	T3 to T2		HR (95%CI): 1.79 (0.64-4.96)	
	T3 to T1		HR (95%CI): 2.50 (0.83-7.50)	
	T2 to T1		HR (95%CI): 1.40 (0.44-4.46)	
	Vertical impuls (BW/s) in tertiles	46		+
	T3 to T2		HR (95%CI): 0.74 (0.28-1.94)	
	T3 to T1		HR (95%CI): 2.02 (0.47-8.63)	
	T2 to T1		HR (95%CI): 2.74 (0.75-10.01)	
	Vertical impact transient (BW/s) in tertiles	46		+
	T3 to T2		HR (95%CI): 1.03 (0.40-2.65)	
	T3 to T1		HR (95%CI): 1.46 (0.48-4.41)	
	T2 to T1		HR (95%CI): 1.42 (0.40-5.05)	
	Instantaneous vertical loading rate (BW/s) in tertiles	46		+
	T3 to T2		HR (95%CI): 1.19 (0.41-3.46)	
	T3 to T1		HR (95%CI): 1.49 (0.44-5.08)	
	T2 to T1		HR (95%CI): 1.26 (0.45-3.52)	
Peak				
	Active peak (BW/s) in tertiles (females)	46	HR (95%CI): 0.59 (0.20-1.77)	+
	T3 to T2		HR (95%CI): 0.55 (0.19-1.60)	
	T3 to T1		HR (95%CI): 0.92 (0.29-2.91)	
	T2 to T1			
Other	Higher running intensity (RPE score)	15	**HR (95%CI): 1.28 (1.23-8.75)**	+
	Type of running shoes; new versus used (ref)	16	HR (95%CI): 1.22 (0.79-1.89)	+
	Type of running shoes; other versus used (ref)	16	HR (95%CI): 1.84 (0.96-3.52)	
	Higher Peak Breaking Force (PBF= BW<-0.23) in regard to lower PBF (-0.27 - -0.23 BW).	46	**OR (95%CI): 5.08 (1.71-15.03)**	+
	Loading rate	36	HR (95%CI): 1.01 (1.00-1.02)	+
	Health related factors			
Previous injury	Having had a previous RRI	16	HR (95%CI): 1.29 (0.75-2.22)	+++
	Having had a previous RRI >12 months ago	20	**HR (95%CI): 1.88 (1.03-3.45)**	
	Having had a previous RRI	22	cIRD (95%CI): 5.2% (-8.9 – 19.3%)	
	Having had a previous RRI (males) >3 to <12 months versus no RRI	14	**HR (95%CI): 2.64 (1.32-5.30)**	++
	Having had a previous RRI (males) >12 months versus no RRI	14	HR (95%CI): 2.14 (1.05-4.35)	
	Having had a previous injury not attributed to running	16	**HR (95%CI): 1.78 (1.26-2.53)**	++++
	Having had a previous injury not attributed to running	22	**cIRD (95%CI): 11.1% (-0.2 – 22.4%)**	

Bold= significant risk factor; *only univariable analyses; BW=bodyweight; GRADE classification +=very low quality evidence, ++=low quality evidence, +++=moderate quality evidence, ++++=high quality evidence. BMI= Body Mass Index; COF= center of force.

Appendix F: risk factors in long distance runners

	Potential Prognostic factor	Ref	Estimated effect	GRADE
Personal factors				
Age	Age; Per year younger (females)	53	**RR: 1.42 (95% CI; 1.05-1.92)**	+
BMI	Weight	55	OR (95%CI): 1.06 (0.95-1.05)	+
Sex	Sex	54	RR (95%CI): 0.76 (0.41-1.39) (males) RR (95%CI): 1.32 (0.72-2.44) (females)	++
	Sex	55	OR (95%CI): 1.147 (0.48-2.73)	
Other	Age at menarche: Age per year younger	53	**RR: 1.92; (95% CI; 1.15-3.23)**	+
	Bone mineral content	53	**RR: 2.70 (95% CI; 1.26-5.88)**	+
	Neovascularization of the Achilles tendon grade 1	51	**OR (95%CI): 6.9 (2.6-18.8)**	+
	Funct Movement Screening; Drop squat & ASLR score ≤3	52	**OR (95%CI): 9.7 (2.1-44.4)**	+
	Leg length difference	50	OR (95%CI): 1.3 (0.6-2.7	+
	Lower calcium intake	53	RR: 1.11 (95% CI; 0.98-1.25)	+
	No more than 9 menstrual periods per year	53	OR (95%CI): 3.41 (0.69-16.91)	+
	Q-angle	50	OR (95%CI): 0.9 (0.8-1.0)	+
	Subtalar-angle	50	OR (95%CI): 1.0 (0.8-1.2)	+
	Plantar arch index -Normal (0.21-0.26) -High (<0.21) -Low (>0.26)	50	 OR (95%CI): 1.0 (ref) OR (95%CI): 1.0 (0.3-3.1) OR (95%CI): 1.0 (0.3-3.8)	+
	Running experience -1 to 2 years college running -3 to 4 years college running	54 54	RR (95%CI): 1.74 (0.81-3.73) RR (95%CI): 0.57 (0.27-1.23)	+
	Dominant vs non-dominant leg	55	OR (95%CI): 1.06 (0.62-1.82)	+
	SF-12	55	OR (95%CI): 0.96 (0.89-1.04)	+
	PANAS	55	OR (95%CI): 1.05 (0.95-1.12)	+
Training related factors				
Training volume	-<64.4 km/wk ->64.4 km/wk	54 54	RR (95%CI): 1.44 (0.79-2.62) RR (95%CI): 0.69 (0.38-1.27)	+
Training duration	Duration of training session	49	**OR (95%CI): 1.01 (1.00-1.02)**	+
Type of training	Performing interval training Performing speed training	49	**OR (95%CI): 0.61 (0.43-0.88)** **OR (95%CI): 1.46 (1.02-2.10)**	+
Other	Training pace, min/mile	55	OR (95%CI): 1.06 (0.73-1.50)	+
	Type of surface, most times per week -Hard -Other	49	 OR (95%CI): 1.06 (0.86-1.31) OR (95%CI): 0.25 (0.05-1.25)	+
	Type of terrain, times per week -Uphill -Downhill	49	 OR (95%CI): 0.65 (0.38-1.13) OR (95%CI): 0.12 (0.01-1.75)	+
	Max ground reaction force	55	OR (95%CI): 1.0 (0.996-1.001)	+
	Maximum propelling force	55	OR (95%CI): 1.0 (0.987-1.009)	+
	Max knee stiffness	55	**OR (95%CI): 1.18 (1.02-1.37)**	+
	Medial ground pressure in stance	48	**Crude cumulative risk difference % (95%CI); 1000km: 0.10 (0.01-0.19); 1500km: 0.16 (0.03-0.28);** 100 km: 0.006 (-0.05-0.06); 250 km: 0.018 (-0.04-0.08); 500 km: 0.04 (-0.02-0.11)	+
Health related factors				
Previous running related injury	Previous running related injury	49 51 54	**HR (95%CI): 1.88 (1.01-3.51)** **OR (95%CI): 3.8 (1.70-8.50)** **RR (95%CI): 2.34 (1.01-5.42)**	+++
	Previous running related injury (females)	53	**RR (95%CI): 6.42 (1.80-22.87)**	+

Bold= significant risk factor; *=only univariable analysis; GRADE classification +=very low quality evidence, ++=low quality evidence, +++=moderate quality evidence, ++++=high quality evidence. BMI= Body Mass Index.

Appendix G: Grading assessment quality of evidence **(GRADE)**

Prognostic factor	Nr of studies	Nr of participants	Phase	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Effect size	Dose effect	Overall quality
Short distance runners											
Personal factors											
Age (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
Age (males)	1	875	1	V	↓	V	↓	x	x	x	++
Age (females)	3	2322	1	↓	↓	V	V	x	x	x	++
BMI (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
BMI (males)	3	2322	1	↓	↓	V	V	x	x	x	++
BMI (females)	1	875	1	V	↓	V	↓	x	x	x	++
Sex	3	3580	1	V	↓	V	V	x	x	x	+++
Running experience (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
Running experience (males)	1	875	1	V	↓	V	↓	x	x	x	++
Running experience (females)	1	875	1	V	↓	V	↓	x	x	x	++
Previous sports participation (generic)	3	3138	1	V	V	V	V	x	x	x	++++
Previous sports participation (males)	2	1478	1	V	↓	V	↓	x	x	x	++
Previous sports participation (females)	1	875	1	V	↓	V	↓	x	x	x	++
Behaviour (generic)	1	933	1	V	↓	V	↓	x	x	x	++
Behaviour (males)	1	603	1	V	↓	V	↓	x	x	x	++
Foot morphology (generic)	2	1384	1	V	↓	V	↓	x	x	x	++
Foot morphology (females)	1	603	1	↓	↓	V	↓	x	x	x	++
Extension MTP 1	1	433	1	↓	↓	V	↓	x	x	x	+
Training related factors											
Frequency (generic)	2	2526	1	↓	V	V	V	x	x	x	+++
Frequency (females)	1	844	1	↓	↓	V	↓	x	x	x	+
Lower weekly volume (min)	2	2526	1	↓	V	V	V	x	x	x	+++
Distance (km)	2	1366	1	V	↓	V	↓	x	x	x	++
Type of running terrain (generic)	1	433	1	V	↓	V	↓	x	x	x	+ +
Running shoe age (generic)	2	2526	1	V	V	V	V	x	x	x	++++
Running shoe age (males)	1	844	1	↓	↓	V	↓	x	x	x	+
Running shoe age (females)	1	844	1	↓	↓	V	↓	x	x	x	+
Hip ABDuction strength (generic)	1	832	1	↓	↓	↓	↓	x	x	x	+
COF displacement (generic)	1	129	1	↓	↓	↓	↓	x	x	x	+
COF displacement (females)	1	131	1	↓	↓	V	↓	x	x	x	+
Force distribution (generic)	1	129	1	↓	↓	↓	↓	x	x	x	+
Force distribution (females)	1	131	1	↓	↓	V	↓	x	x	x	+
Fmax lateral heel	1	129	1	↓	↓	V	↓	x	x	x	+
Active peak (females)	1	74	1	V	↓	V	↓	x	x	x	++
Peak braking force	1	74	1	V	↓	V	↓	x	x	x	+ +
Intensity	1	1772	1	↓	↓	V	↓	x	x	x	+
Hip internal rotation	1	875	1	V	↓	V	↓	x	x	x	+ +
Hip-waste ratio	1	1772	1	V	↓	V	↓	x	x	x	+ +
Type of running shoes	1	1772	1	V	↓	V	↓	x	x	x	+ +
Vertical loading rate	1	74	1	V	↓	V	↓	x	x	x	+ +
Vertical impulse	1	74	1	V	↓	V	↓	x	x	x	+ +
Vertical impact transient	1	74	1	V	↓	V	↓	x	x	x	+ +
Instantaneous vertical loading rate	1	74	1	V	↓	V	↓	x	x	x	+ +
Loading rate	1	238	1	↓	↓	V	↓	x	x	x	+
Type of running terrain (generic)	1	433	1	V	↓	V	↓	x	x	x	+ +
Health related factors											
Previous RRI (generic)	3	3138	1	V	↓	V	V	x	x	x	+++
Previous RRI (males)	1	603	1	V	↓	V	↓	x	x	x	++
Previous injury not attributed to running	2	2705	1	V	V	V	V	x	x	x	++++
Long distance runners											
Personal factors											
Age (females)	1	150	1	↓	↓	↓	↓	x	x	x	+
Weight	1	150	1	↓	↓	↓	↓	x	x	x	+
Sex	2	388	1	↓	V	V	↓	x	x	x	++
Age at menarch	1	150	1	↓	↓	↓	↓	x	x	x	+
Bone mineral content	1	150	1	↓	↓	↓	↓	x	x	x	+
Functional movement screen (Drop Squat/ASLR)	1	101	1	↓	↓	V	↓	x	x	x	+
Neovascularisation grade I Achilles Tendon	1	634	1	↓	↓	↓	↓	x	x	x	+
Leg length difference	1	89	1	↓	↓	V	↓	x	x	x	+
Calcium intake	1	150	1	↓	↓	↓	↓	x	x	x	+
Mentrual irregularity	1	150	1	↓	↓	↓	↓	x	x	x	+
Q-angle	1	89	1	↓	↓	V	↓	x	x	x	+

Prognostic factor	Nr of studies	Nr of participants	Phase	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Effect size	Dose effect	Overall quality
Subtalar angle	1	89	1	↓	↓	V	↓	x	x	x	+
Plantar arch index	1	89	1	↓	↓	V	↓	x	x	x	+
Running experience	1	88	1	↓	↓	V	↓	x	x	x	+
Dominant leg	1	300	1	↓	↓	V	↓	x	x	x	+
SF-12	1	300	1	↓	↓	V	↓	x	x	x	+
PANAS	1	300	1	↓	↓	V	↓	x	x	x	+
Training related factors											
Volume (km per week) (female)	1	150	1	↓	↓	↓	↓	x	x	x	+
Duration (of training session)	1	200	1	↓	↓	V	↓	x	x	x	+
Type of training (IV/Speed)	1	200	1	↓	↓	V	↓	x	x	x	+
Medial shoe ground pressure in stance (500/1000km per week)	1	99	1	V	↓	↓	↓	x	x	x	+
Knee stiffness	1	300	1	↓	↓	↓	↓	x	x	x	+
Intensity/pace	1	300	1	↓	↓	V	↓	x	x	x	+
Type of surface/terrain	1	200	1	↓	↓	V	↓	x	x	x	+
Max GRF	1	300	1	↓	↓	V	↓	x	x	x	+
Max PRP force	1	300	1	↓	↓	V	↓	x	x	x	+
Medial shoe ground pressure in stance (100km/250km/500km per week)	1	99	1	V	↓	↓	↓	x	x	x	+
Health related factors											
Previous RRI	3	922	1	↓	V	V	↓	x	↑	x	+++
Previous RRI (female)	1	150	1	↓	↓	↓	↓	x	x	x	+

Generic includes both male and female runners. V=no serious limitations, ↓=serious limitations (x= not applicable). If only 1 study was found with significant results downgrading was done for inconsistency and imprecision. For overall quality of evidence: +very low; ++ low; +++ moderate; ++++ high. If studies presented no data from multivariate analysis they were excluded from the GRADE. COF= center of force; GRF= Ground reaction force; PRP=propelling force

Appendix H: PROBAST; rating the evidence of risk models for RRIs

Study	Type of prediction model study		RoB				Applicability			Overall	
	Development / validation	Diagnostic / Prognostic	Participants	Predictors	Outcome	Analysis	Participants	Predictors	Outcome	RoB	Applicability
Wen, et al. 19998	Development	Prognostic	+	+	+	-	+	+	+	+	+
van Middelkoop, et al. 2008	Development	Prognostic	-	+	+	-	-	+	+	-	-
van Poppel, et al. 2016	Development	Prognostic	+	+	+	-	+	+	+	+	+
van Poppel, et al., 2018	Development	Prognostic	+	+	+	-	+	+	+	+	+

PROBAST = Prediction model Risk Of Bias Assessment Tool; ROB = risk of bias.
* + indicates low ROB/low concern regarding applicability; – indicates high ROB/high concern regarding applicability; and ? indicates unclear

Chapter 4

Risk factors for lower extremity injuries among half marathon and marathon runners of the Lage Landen Marathon Eindhoven 2012: A prospective cohort study in the Netherlands.

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Scand J Med Sci Sports. 2016 Feb;26(2):226-34. doi: 10.1111/sms.12424. Epub 2015 Feb 28.PMID: 25727692.

Abstract

Objective: To determine risk factors for running injuries during the Lage Landen Marathon Eindhoven 2012.

Design: Prospective cohort study.
Setting: Population based

Participants: In total 943 runners participated in this study.

Main outcome measure: running injuries after the Lage Landen Marathon

Assessment of Risk factors: Sociodemographic factors, training related factors and lifestyle factors were considered as potential risk factors and assessed in a questionnaire one month before the running event. The association of potential risk factors and injuries were analyzed per running distance separately by univariate and multivariate logistic regression analysis.

Results: A total of 154 respondents sustained a running injury at the running event. BMI over 26 kg/m^2, less than five years of running experience and often performing interval training were univariate significantly associated with running injuries among half marathon runners. In the multivariate model, only less than five years of running experience and not performing interval training on a regular basis were significantly associated with running injuries. In marathon runners no multivariate model could be created because of low number of injuries and participants.

Conclusions: Interval training on regular basis may be advised to half-marathon runners to reduce the risk of injury.

Introduction

Long-distance running is very popular among recreational sports participants[1-3]. In 2008, approximately 11.5% of the population in the USA ran, and 3.4% of this group ran on average two times a week or more[4]. It is estimated that 36% of the Europeans aged between 15 to 65 years are recreational runners

[http://www.everythingaboutrunning.asics.eu/]. In 2012, 1.900.000 Dutch people performed running activities[5]. It is estimated that 610.000 running injuries occurred in 2012 in the Netherlands[5].

Most running related injuries occur in the lower extremities[1,3,5-8]. A systematic review showed that the incidence of lower extremity running injuries ranged from 19.4 to 79.3%[1]. The most common anatomical site of running injuries is the knee[2,3].

Risk factors for running injuries have been extensively discussed in literature[6,7,9-17]. Because of the heterogeneity of the studies performed (e.g. definition of an injury, type of runners recreational or elite and short or long distance runners), the literature does not provide a clear overview of the most important risk factors for running injuries.

In literature, increased training volume per week in male runners and a history of previous injuries for runners were identified as statistically significant risk factors for running injuries[1]. There is conflicting evidence for other risk factors, such as age and sex[6,9,14,15,18], training distance[7-9,13], running experience[19], body mass index (BMI)[15] and use of orthotics[8,20]. Despite the common belief that factors like running terrain, types of shoes and training characteristics (duration, frequency of running, running speed, warm-up and exercise habits before running) might be associated with running injuries, there is no evidence for an association[10-12,21]. This could be due to differences in study groups in the respective studies.

In previous systematic reviews, potential risk factors for running injuries were assessed in one heterogeneous group ranging from running distances of five km to marathon distances (42.195km)[1,22]. Differences in training characteristics such as mileage, duration, frequency and intensity of training between these different running distances could be expected. A recent study indeed showed that half marathon runners had fewer years of experience ($P < 0.05$), completed fewer weekly training kilometers ($P < 0.001$), and fewer weekly running hours ($P < 0.01$) compared to marathoners[23]. If such factors differ between marathon and half marathon runners and are potential risk factors for injuries, we hypothesize that that the incidences and risk factors of running injuries differ between half marathon and marathon runners. To the best of our knowledge, no studies prospectively evaluated the incidence of running injuries and such possible risk factors for running injuries in recreative male and female runners in marathon (42.195km), half marathon (21.095 km) during one event separately. Therefore, the aim of this study is to assess 1) the incidence of running injuries in half marathon and marathon runners and 2) risk factors for running injuries in the lower extremities of runners on half marathon and marathon.

Methods

Study participants

Participants for the Lage Landen Marathon Eindhoven (October 14, 2012), which is a yearly national running event, were invited for this study. The runners participated in different distances, marathon (42.195 km), half marathon (21.095 km), relay marathon (10.5 km), city run (5 km) or mini marathon (2.5 km). During this event also the Dutch national championship marathon running was held.

Participants were included if: they were recreational runners, ran marathon, half marathon. Exclusion criteria were: subscription within 4 weeks from the start of the event, no email address available, competition runners, company runners, relay runners or no baseline information available.

The Medical Ethical Committee of the Erasmus Medical Centre Rotterdam, the Netherlands, approved this study.

Data collection

Out of the 14155 participants, in total 5304 participants (37.5%) received an invitation to by email to participate in this study. They received a link to an online baseline questionnaire, one month before the Lage Landen Marathon Eindhoven (T0). These questionnaires were developed and used before, in the Singelloop Breda study[3] and study from van Middelkoop[2]. All participants who returned the baseline questionnaire, were included and received a follow-up questionnaire one week after the event (the questionnaire is available from the authors when requested). A reminder was sent by email within one week to the non-responders.
At baseline, runners were asked to complete questions about demographic characteristics (age, sex, height, weight), training variables (weekly training frequency, weekly running distance, running speed during training, type of training, running terrain, warming up routine and type of running shoes), years of running experience, lifestyle (other sports, smoking, alcohol, nutritional and overall health) and previous running injuries during the last year (location of injuries and current injury).
The follow-up questionnaire (T1) obtained information regarding the running event (running distance and performance), new running injuries during the Lage Landen Marathon Eindhoven, location of injuries, and pain intensity measured with an 11-point Numeric Rating Scale (NRS)[24,25].

Risk factors

Risk factors of interest were training characteristics namely: weekly kilometers of running last weeks before the event, weekly frequency of running, running terrain and type of training. Training distance, frequency of running and running experience were categorized into three groups[7].
Running terrain (hard, not hard, tartan), training type (long-distance training and interval training), warming-up, cooling down and stretching activities had the following answer options: always, often, sometimes, rarely, or never. Always and often were categorized as 'often'. Sometimes, rarely and never as 'sometimes', like one other study[13]. Other factors of interest were sociodemographic variables such as age, gender and BMI. BMI was categorized into three groups (20<, 20-26, >26)[12]. Previous injuries in twelve months preceding the event was asked in format yes or no.

Outcome

The outcome of interest was the presence of new running injuries during the Lage Landen Marathon Eindhoven reported at follow-up (T1). Running injuries are defined as self-reported complaints of muscles, joints, tendons or bones in the lower extremity (hip, groin, thigh, knee, lower leg, ankle, foot and toe) due to running activities. These complaints have to reduce the running intensity or frequency, or need medical consultation[3,13,18].

Statistical analysis

Runners were categorized into two groups based on their running distance during the event: marathon (42.195 km) and half marathon (21.095 km). Descriptive statistics, were calculated for baseline characteristics, including frequencies for categorical variables and means and standard deviations (in case the data did not show a normal distribution, medians and interquartile ranges (IQR)) for continuous variables. Incidence rates were calculated according to consensus statement from Timpka (2014)[26]: 1) in-competitions injuries as number of injuries per 1000 athletes and 2) overall incidence as number of injuries per exposure hours during competition.
To evaluate possible risk factors all determinants were first independently analyzed using an univariate logistic regression analyses for the participants on marathon and marathon

separately. Correlations between all potential factors were calculated by Spearman's rho test. If a correlation between two factors was ≥ 0.8 only one of the risk factors for the multivariate analyses was chosen. Factors with a p-value ≤ 0.20 in the univariate models were entered in multivariate logistic regression model. Forward stepwise entering was used and p ≤ 0.10 was used as a cut off level for acceptance. No more than a single variable was chosen for every 10 injuries in the analysis[27]. Data were analyzed using the Statistical Package for Social Sciences (SPSS version 22, Inc, Chicago, Illinois).

Results

Participants

In total 943 runners (17.8%) returned the baseline questionnaire of which 39 missed baseline information and were therefore excluded. Only 40 relay marathon runners responded and because of their low number were also excluded. In total 614 runners (71.1%) of these 864 runners responded to the follow-up questionnaire as presented in the flow chart (Figure 1) and were included for analysis. A total of 150 participants ran the marathon, 464 participants ran the half marathon. Of all included participants, a total of 570 participants (92.9%) started and finished their run, eight participants started but did not finish, and 36 persons did not start because of sickness or injuries.
At follow up, 142 runners (23.1%) reported a total of 209 new injuries after the race. Runners in the full marathon group had the lowest incidence rate of in-competition injuries with 226 injuries per 1000 athletes, followed by the half marathon group with 237 injuries per 1000 athletes. Most of the injuries occurred in the knee (18.7%).

Baseline characteristics

The mean age of the runners was 43.7 years (SD, 11.2 years); 67.1% were male and the average BMI was 23.1 kg/m^2 (SD, 2.5 kg/m^2). The demographic characteristics, training-related characteristics, lifestyle and running injuries are presented in Table 1. No differences were found between responders and non-responders (P<0.05). About 60% of the runners suffered one or more running injuries during the year preceding the baseline questionnaire. Almost 55% of the runners had over five years of running experience. Training-related characteristics were similar between half marathon and marathon runners. Most runners (87.0%) ran mostly on hard underground, whereas 27.0% also reported to run mostly on soft underground. Long-distance training is the most frequently used training in all groups (93.1%). In total 44.1% of the runners also

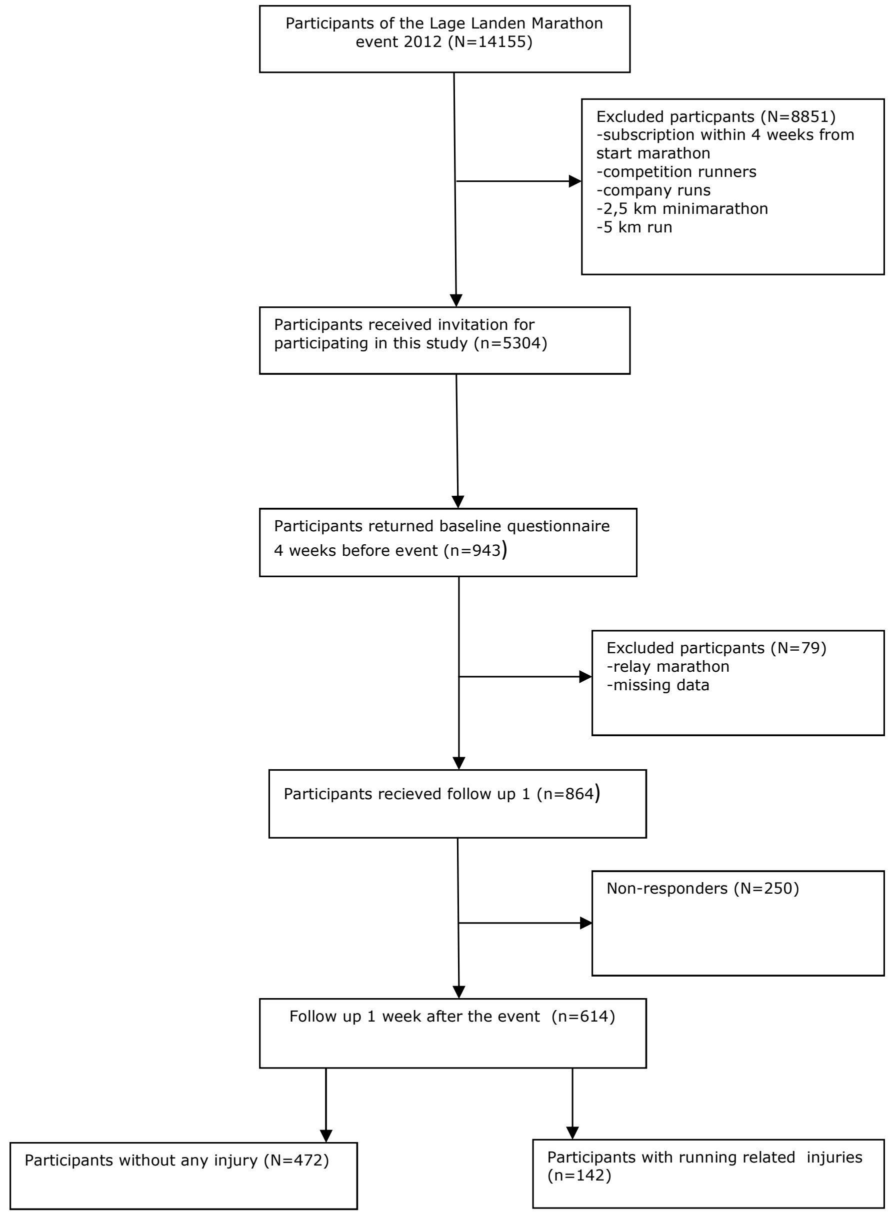

Figure 1: flowchart Lage Landen Marathon Eindhoven 2012

used interval training. The incidence per 1.000 hours running was 107 injuries. Categorizing runners by running distance the incidence was 131 injuries per 1.000 hours of running among half marathon runners and 66 injuries per 1000 hours of running among marathon runners.

Table 1: Population characteristics

	Half marathon n = 464	Marathon n = 150	Total n = 614
	Number (%)	Number (%)	Number (%)
Gender males	311 (67.0%)	103 (68.7%)	414 (67.4%)
Age (years), mean (SD)	43.6 (11.4)	44.0 (11.1)	43.8 (11.2)
< 20	46 (9.9%)	16 (10.7%)	62 (10.0%)
20-26	362 (77.7%)	118 (78.6%)	480 (78.2%)
> 26	58 (12.4%)	16 (10.7%)	74 (12.1%)
Previous injury 12 months (% yes)	285 (61.2%)	82 (54.7%)	367 (59.8%)
0-4	221 (47.4%)	59 (39.3%)	298 (45.6%)
5-10	112 (24.0%)	49 (32.7%)	161 (26.2%)
> 10	133 (28.5%)	42 (28.0%)	175 (28.5%)
Trainings distance (km/week)			
< 20	119 (25.5%)	39 (26.0%)	158 (25.7%)
20-40	226 (48.5 %)	65 (43.3%)	291 (47.4%)
> 40	121 (26.0)	46 (30.7%)	167 (27.2%)
Training frequency (times/week)			
0-2	19 (4.1%)	1 (0.7%)	20 (3.3%)
2-5	434 (93.1%)	144 (96.0%)	578 (94.1%)
> 5	13 (2.8%)	5 (3.3%)	18 (2.7%)
Running speed (km/h), median (IQR)	11.0 (2.0)	11.0 (2.0)	11.0 (2.0)
Hard training underground (% often)	406 (87.1%)	130 (86.7%)	536 (87.3%)
No hard training underground (% often)	127 (27.3%)	40 (26.7%)	167 (27.2%)
Tartan training underground (% often)	48 (10.3%)	18 (12.0%)	66 (10.7%)
Long-distance training (% often)	433 (92.9%)	140 (93.3%)	573 (93.3%)
Interval training (% often)	213 (45.7%)	61 (40.7%)	274 (44.6%)
Warming-up before training (% often)	215 (46.1%)	71 (47.3%)	286 (46.6%)
Stretching before training (% often)	237 (50.9%)	67 (44.7%)	304 (49.5%)
Cooling down after training (% often)	194 (41.6%)	65 (43.3%)	2595 (42.2%)
Stretching after training (% often)	299 (64.2%)	82 (54.7%)	381 (62.1%)
Organized running in groups (% yes)	210 (45.1%)	62 (41.3%)	272 (44.3%)
Shoe advice (% yes)	406 (87.1%)	131 (87.3%)	537 (87.5%)
Participation other sports (% yes)	290 (62.2%)	89 (59.3%)	379 (61.7%)
Daily smoking (% yes)	17 (3.6%)	6 (4.0%)	28 (3.7%)
Alcohol use (glasses/week), median (IQR)	4.0 (6.0)	4.0 (6.0)	4.0 (6.0)
Special feeding supplements (% yes)	136 (29.2%)	51 (34.0%)	187 (30.5%)
Running injuries (% yes)	110 (23.6%)	34 (22.7%)	144 (23.5%)

SD: standard deviation; IQR: interquartile range; BMI: body mass index; kg: kilogram; m: meter; km: kilometers; h: hours

Risk factors

Univariable analysis

Among half marathon runners, analysis revealed five risk factors (Table 2) independently associated with running injuries ($p<0.20$). These factors were gender (OR 1.44; CI 0.90-2.32), BMI over 26 kg/m^2 (OR 3.00; CI 1.08-8.34), less than five years of running experience (OR 1.77; CI 1.07-2.92), not performing regular interval training (OR 0.55; CI 0.35-0.85) and weekly training frequency of one time per week (OR 0.25; CI 0.04-1.45). Three of these associated factors were significant risk factors by univariate analysis ($p<0.05$); BMI (>26), running experience (0-4 years) and not performing interval training (often).

Among marathon runners we found eight risk factors (Table 2) associated with running injuries ($p<0.20$). BMI over 26 kg/m^2 (OR 0.24; CI 0.40-1.43), weekly training distance less than 20 km/week (OR 0.47; CI 0.17-1.32), weekly training frequency over five times per week (OR 5.70; CI 0.91-35.67), tartan surfaces (OR 2.48; CI 0.88-6.99), performing regularly interval training (OR 1.91; CI 0.88-4.13), performing regularly cooling down (OR 1.93; CI 0.89-4.17), stretching afterwards (OR 1.71; CI 0.78-3.78) and organized

Table 2: Univariate odds ratios (ORs) for running injuries versus no injuries in runners of the half marathon and marathon group

	Half marathon (n = 466)			Marathon (n = 150)		
Variables	OR	95% CI	P-value	OR	95% CI	P-value
Age (years)	0.99	0.97 - 1.01	0.22	0.99	0.96 - 1.03	0.47
Gender (male)	1.44	0.90 - 2.32	0.13*	0.26	0.56 - 2.83	0.57
BMI (kg/m^2)						
< 20	1.44	0.79 – 2.65	0.24	0.51	0.11 – 2.37	0.39
20-26	1		0.11*	1		0.24
> 26	**3.00**	**1.08 – 8.34**	**0.04***	0.24	0.40 – 1.43	0.12*
Previous injury (yes)	0.83	0.53 - 1.29	0.41	0.91	0.43 - 1.97	0.82
Running experience (years)						
0-4	**1.77**	**1.07 – 2.92**	**0.03***	1.390	0.55 - 3.54	0.49
4-10	1.19	0.68 – 2.09	0.55	1.226	0.47 – 3.21	0.68
> 10	1		0.07*	1		0.79
Training distance (km/week)						
< 20	0.93	0.51 – 1.71	0.82	0.47	0.17 – 1.32	0.15*
20-40	1		0.91	0.77	0.30 – 2.01	0.59
> 40	0.89	0.53 – 1.51	0.67	1		0.33
Training frequency (times/week)						
0-2	0.25	0.04 – 1.45	0.12*	0.00	0.00	1.00
2-5	1		0.14*	1		0.18*
> 5	0.61	0.13 – 2.79	0.52	5.70	0.91 – 35.67	0.06*
Hard underground (often)	0.68	0.38 - 1.25	0.21	0.86	0.29 - 2.57	0.79
No hard underground (often)	1.20	0.75 - 1.91	0.46	0.70	0.30 - 1.60	0.40
Tartan underground (often)	0.84	0.40 - 1.74	0.63	2.48	0.88 - 6.99	0.09*
Long distance training (often)	1.42	0.57 - 3.54	0.45	0.66	0.16 - 2.72	0.57
Interval training (often)	**0.55**	**0.35 - 0.85**	**0.01***	1.91	0.88 - 4.13	0.10*
Warming up before training (often)	0.84	0.54 - 1.29	0.41	1.34	0.62 - 2.88	0.46
Stretching before training (often)	1.10	0.72 - 1.69	0.65	0.97	0.45 - 2.10	0.94
Cooling down after training (often)	0.83	0.54 - 1.29	0.40	1.93	0.89 - 4.17	0.10*
Stretching after training (often)	1.08	0.69 - 1.69	0.75	1.71	0.78 - 3.78	0.18*
Organized running in groups (yes)	1.19	0.77 - 1.83	0.43	0.54	0.25 - 1.17	0.12*
Shoe advice (yes)	0.79	0.40 - 1.54	0.48	1.11	0.34 - 3.61	0.86
Participation other sports (yes)	0.97	0.63 - 1.51	0.90	1.03	0.47 - 2.24	0.95
Daily smoking (yes)	0.88	0.61 - 1.28	0.51	0.99	0.51 - 1.92	0.96
Alcohol use (glasses/week)	1.22	0.69 - 2.17	0.50	1.02	0.93 - 1.10	0.73
Special feeding supplements (yes)	1.36	0.83 - 2.21	0.22	0.93	0.42 - 2.07	0.86

OR > 1.00 is a risk factor; OR < 1.00 is a protective factor; CI, confidence interval; * entering multivariate model p < 0.20; Bold: significance p < 0.05

Table 3. Multivariate regression model (forward stepwise) for running injuries versus no injuries in runners of the half marathon (n = 466)

Variables	OR	95% CI	P-value
Running experience			
< 5 years	**1.87**	**1.13 - 3.11**	**0.02**
5-10 years	1.14	0.64 - 2.01	0.66
> 10 years (reference)	1		0.04
Interval training (always vs sometimes)	**0.67**	**0.33 - 0.81**	**< 0.01**
Nagelkerke R square			**0.045**

Only entered variables shown; OR, odds ratio; CI, confidence interval

In the marathon group injury rate was rather low, so a multivariate logistic regression model to assess the combined effect of the eight factors univariately found, could not be performed.

Discussion

This study assessed the incidence of running injuries and the risk factors for running injuries in the lower extremities of half marathon, and marathon runners. We found an incidence rate of 23.5%, and 16.9 injuries per hour training in the total study sample. Also, we found less than five years of running experience and not often performing interval training to be significantly associated with running injuries of the lower extremity in the half marathon group. In the short distance group and the marathon group it was not possible to calculate a risk model due to the relative small number of participants and injuries in these distances.

Comparison with other studies

In this study incidence of lower extremity injuries in the half marathon group was 23.6%. This percentage is lower than in another study, which reported 42.4% among half marathon runners[7]. A possible explanation could be training distance per week. In this study 74.5% of the runners ran over 20 km/week and 52.5% of the runners ran over five years, compared to the other study in which 35.5% ran over 20 km/week and 35.4% had over five years of running experience[7]. We assume that runners in our study may have developed musculoskeletal adaptation to running due to a higher weekly training distance and more years of running experience. Therefore they are less predisposed to develop injuries during long distances running[13,17].

This study revealed that rate of running injuries in marathon was 22.7%, this percentages lies within the range of 18.2-23.8% as observed in previous studies among marathon runners[2,9]. Due to lack of information about training-related characteristics comparison between our study and previous studies is restricted[9].

Van Middelkoop et al. (2008b) reported an average weekly distance among marathon runners of 50.2 km (SD 18.3km) and 21.3% ran over 60 km per week, whereas in this study marathon runners 30.7% ran over 40 km per week[13]. Other training-related variables were similar to our study. Therefore, it could be suggested that the lower rate of RRIs reported by Van Middelkoop (2008b) was due to higher weekly training distance[13]. Several authors showed that female gender is a risk factor for running injuries in comparison with males[28,29]. This could explain, why the incidence rates in our study were higher than the previous studies of van Middelkoop as this study also included females (31.3%). Another explanation could be that most of our runners in training ran 30 km or less per week. Earlier research showed that d that incidence of running injuries was lower when runners run more than 30 km weekly[17].

A higher amount of training is reported to be a risk factor for injuries in endurance athletes[30]. Exposure time in marathons is over twice as long as in the half marathon (world record marathon is 2:02:75 in Berlin marathon 2014 and half marathon 58:23 in Lissabon 2010), and a recent study showed that running characteristic differed between half marathon runners and marathon runners in terms of experience, weekly training kilometers and weekly running hours[23]. Half marathon runners had fewer years of experience, completed fewer weekly training kilometers, and fewer weekly running hours compared to the marathoners. It was hypothesized that the percentage of running injuries would be higher in the marathon group than in the half marathon group and training-related characteristics would differ between both groups.

Therefore, a higher mileage per week (44.7 km/week) and a higher weekly training frequency (3.7 training units a week) and speed (11.1. km/hrs) were to be expected in marathon runners[23,31,32]. However, both our groups showed little differences in training-related characteristics. An explanation for the similar rate of running injuries occurring in both groups could be that runners switched their running distance. Meaning participants who subscribed for the marathon ran half a marathon. Additionally, half marathon runners in this race event could be in training for a marathon later that year as well.

Weekly running frequency was also quite similar between half marathon and marathon runners and was not significantly associated with running injuries. This study reveals that in the half marathon group 2.8% and in the marathon group 3.3% ran over five times/week, whereas another study reported respectively 23.9% and 50.4% weekly running frequency over five times/week[7]. It remains unclear why only 3.3% of the marathon runners in this study trained more than 5 times a week. A possible explanation could be that we excluded competition runners which are more likely to training more frequent than recreational runners.

The population Chang used is different with this study because 87.4% of the participants were males while in this study 67.4% were males. But, this does not explain the differences in training frequency. A possible explanation could be that half marathon and marathon runners from this study seems to run less frequent but more distance than in the study from Chang in which runners ran more frequent but with smaller distance. Only 2.7% from the runners in this study ran 5 times or more per week in comparison with Chang were 31.1% ran 5 times or more per week. In total 15.4% of the runners in that study ran over 40 km a week[7] while in our study 27.2% ran at least 40 km per week. Although the results in this study differ from the results reported by Chang (2012), we also did not found a significantly association between weekly frequency and running injuries in both groups. A possible explanation could be categorizing of weekly frequency into three groups. The majority of runners (93.9%) reported a weekly frequency between 2-5 times/week. Therefore, we hypothesize that categorizing weekly frequency in a smaller range would make a difference. Running on hard surfaces, like concrete or asphalt roads, was identified as a risk factor for running injuries in some studies[7,18], whereas other studies could not find any association between lower extremity injuries and running terrains[12,18]. Researchers suggested that compared to hard surfaces, softer surfaces (e.g. grass, forest or tartan) provide more shock absorption and were considered to reduce the possibility of getting running injuries and therefore running terrain had a great impact on lower extremity kinematics[9]. Despite 87% of the participants in this study ran on hard surfaces, no association was found with running injuries in both groups. Also, other surfaces were not associated with running injuries in this study, which was confirmed by other studies[1,7,13]. A possible explanation to support the lack of association with running terrain is provided in an earlier study[7]. This study showed that use of soft shoe insoles or insoles with a medical arch can protect runners from having knee pain or hip pain[7]. It is possible that this improves kinematics and reduces shock absorption which might explain why hard surfaces have no association with injuries. On the other hand a randomized-controlled trial showed that routine use of orthotic insoles did not prevent physical-stress-related lower limb injuries in healthy young male adults[33]. Another study reported the use of orthotic insoles was more prevalent in tibial stress injury cases than control subjects (25% vs 5.6%, respectively; $P < 0.02$)[20].

The present study revealed a protective association for interval training in both groups, besides long-distance training, among half marathon runners. This result is in line with an earlier comparable study[13]. These authors reported a lack of interval training as a significant risk factor for the occurrence of knee injuries in marathon runners[13]. This might be a point of future improvement in order to reduce the incidence of running injuries in the lower extremities.

Another risk factor for running injuries also shown in this study was less than five years of running experience. Other studies also identified running experience as a risk factor for running injuries of hamstrings, knee or foot[1,12,13,18]. Whereas, one study showed conflicting evidence between running experience and running injuries[9]. If experienced runners are hypothesized to have developed musculoskeletal adaptation to running compared to novice runners, they are therefore less predisposed to injuries. Additionally, they may be better able to interpret their body's signals and hence train more appropriately before running injuries occur[13,17].

Strengths and limitations

This study has several limitations. Firstly, the response rate at baseline is lower than other comparable studies[3,7,13,17]. However, response rates for e-mail surveys are known to be lower than paper and pencil surveys[34]. This can be an explanation for the lower response rates in our study. Selection bias could not be ruled out because people who are injured are possibly more motivated to participate in the study. Moreover, recall bias could be present but this seems unlikely in the follow up questionnaires because of the short time frame in which participants were asked information about injuries after the event. In regard to the baseline questionnaire recall bias could be present because information was gathered to one year before the event. Following the rules of statistical analysis, not more than one single parameter is chosen for every ten injuries[27], the study sample was too small to perform multivariate analysis in marathon runners.
Thirdly, according to the definition of injuries, an injury is evident as self-reported complaints of muscles, joints, tendons or bones in the lower extremity (hip, groin, thigh, knee, lower leg, ankle, foot and toe) due to running activities. These complaints have to reduce the running intensity or frequency, or need medical consultation. This definition was used before[2,3,13] but is somewhat different from a recent international consensus of defining an injury according to Timka (2014)[26]. Hereby an injury is defined as: "A physical complaint or observable damage to body tissue produced by the transfer of energy experienced or sustained by an athlete during participation in Athletics training or competition, regardless of whether
it received medical attention or its consequences with respect to
impairments in connection with competition or training".

This difference can have caused to an under estimation of running injuries in our study.

Exact diagnosis of injuries remains unknown. Although there was no systematic physical investigation in this study to objectify injuries, authors had a good insight into self-reported pain and discomfort of running injuries reported by runners themselves. Participants may apply the criteria for answering the questions differently. This for example could have led to an overestimation of running related injuries while complaints of post exercise muscle soreness are interpreted as an injury according to our definition. On the other hand there could also be an underestimation while participants did not report any injuries because of the absence of impairments in training or competition and/or medical consultation in regard to the definition from the recent consensus[26]. Therefore our results should be interpreted with caution.

The incidence rate of running injuries could also be biased by a self-selection process of runners, which switched their running distance before the start of the race. Overestimating or underestimating their physical capacity, due to e.g. training, or occurrence of pain preceding the race, could bias incurring of injuries. This can also explain why only a minor difference in training related characteristics between half marathon and marathon runners in our population is reported while greater differences were expected. Also, all outcomes, including running injuries, and determinants were obtained by self-reported questionnaires and the validity of information should be questioned. Self-report studies are inherently biased by the person's feelings at the time they filled out the questionnaire[35]. Thirdly, the final model is weak. It is possible that we have missed other potential risk factors, like psychosocial or other physical factors.

Despite these limitations, the results of this study may contribute to the growing body of knowledge that describes the need for examining the risk and risk factors for injury among half marathon and marathon runners separately.

Conclusion

Our results could not support the hypothesis that the incidence of running injuries differs between different distances of running. Also, risk factors did not differ between marathon and half marathon runners. This study showed that interval training on a regular basis before running a half marathon had a protective effect against running injuries. Less than five years of running experience compared to over ten years of running experience is shown to be a risk factor in half marathon runners.

Medical professionals and coaches could use the findings of this study to advise potential runners and inexperienced runners who want to run a half marathon in order to reduce the risk of running injuries. It seems useful to, perform interval training on a regular basis, to direct costs. However, caution should be taken when interpreting these results, due to possible biased rate of running injuries and possible information bias due to the use of self-reported questionnaires.

Future studies with larger populations allows categorizing of groups and determinants to discriminate between risk factors in regard to different running distances.

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Chapter 5

Risk models for lower extremity injuries among short- and long distance runners: A prospective cohort study.

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Musculoskelet Sci Pract. 2018 Aug;36:48-53. doi: 10.1016/j.msksp.2018.04.007. Epub 2018 Apr 28. PMID: 29729546.

Abstract

Background: Running injuries are very common. Risk factors for running injuries are not consistently described across studies and do not differentiate between runners of long- and short distances within one cohort.

Objectives: The aim of this study is to determine risk factors for running injuries in recreational long- and short distance runners separately.

Design: A prospective cohort study.

Methods: Recreational runners from four different running events are invited to participate. They filled in a baseline questionnaire assessing possible risk factors about 4 weeks before the run and one a week after the run assessing running injuries. Using logistic regression we developed an overall risk model and separate risk models based on the running distance.

Results: In total 3768 runners participated in this study. The overall risk model contained 4 risk factors: previous injuries (OR 3.7) and running distance during the event (OR 1.3) increased the risk of a running injury whereas older age (OR 0.99) and more training kilometers per week (OR 0.99) showed a decrease. Models between short- and long distance runners did not differ significantly. Previous injuries increased the risk of a running injury in all models, while more training kilometers per week decreased this risk.

Conclusions: We found that risk factors for running injuries were not related to running distances. Previous injury is a generic risk factor for running injuries, as is weekly training distance. Prevention of running injuries is important and a higher weekly training volume seems to prevent injuries to a certain extent.

Introduction

Running is an increasingly popular form of physical activity in Western countries.[1,2] In 2008, about 11.5% of the population in the US ran, and 3.4% of this group ran two times a week or more on average.[3] Between 2000 and 2010 the number of half marathon runners in Switzerland increased from 2904 to 8690 female runners and from 9333 to 21583 male runners.[2] In 2012 almost 2 million Dutch people participated in running activities.[4] This is about 11% of the total Dutch population. Although several health benefits are attributed to running activities,[5,6] injuries also occur frequently.[7-10] In the Netherlands about 32% of the runners get injured each year.[4] Most running injuries occur in the lower extremities[11-14] with an incidence varying from 19.4 to 79.3%.[1] This wide variation in incidence is likely due to differences in study-populations and definition of injuries.[8] The most common site of running injuries is the knee.[13-15]

Several studies evaluated risk factors for running injuries.[12,16] The most important risk factors found are: a history of previous injuries and an increased training volume per week in male runners.[1,10,16] The common belief is that factors like body mass index (BMI), running experiences, types of shoes and training characteristics (duration, frequency of running, training distance, running speed, warm-up and exercise habits before running) are also associated with increased risk of running injuries but no statistically significant association has been found yet.[7,9,13,17,18] This may be due to the fact that most research on risk factors for running injuries has been performed in homo- and heterogeneous groups of runners, varying from military personnel to recreational runners, running 5 km to marathon distances (42,195km).[1,18] Training related characteristics such as volume, frequency, duration and intensity of training differ between runners of different distances.[19] Half marathon runners had, compared to marathon runners, significantly less running experience (7.9 years versus 10.5 years), run less weekly training kilometers (minimum weekly distance 16.2 to 45.2 km versus 22.8 to 63.3 km), and run less weekly running hours (3.9 versus 4.8 hrs).[19] Some gender-specific risk factors were also found.[16] Overall, women are at lower risk of developing running related injuries.[16] Previous injuries, running experience (0-2 years), restarting running and having a weekly running distance of more than 40 miles are associated with greater injury risk in men than in women. Age, previous sports, running on concrete surface, participating in marathons, weekly running distance (30-39 miles), and wearing running shoes for 4-6 months were associated with an increased risk of running injuries in females than in males.[16] More females started running, mainly 10 km and half marathons, and the male/female ratio changed from 3:2 to 2:5.[2] In general, risk factors vary between different studies as the result of heterogeneity of the study population, definition of injury, type of runners (recreational or elite) and running distance.[8,14]

No previous studies prospectively evaluated the incidence of running injuries and possible different risk factors for running injuries in recreational short- and long distance runners. Therefore, the aim of this study is to assess the risk factors for running injuries among recreational runners on several running distances during the race and determine whether risk factors differ between the various distances.

Methods

Design

A prospective cohort study with a 12-month follow-up. Runners were invited to participate in the study and were followed-up for 12 months by using web-based questionnaires. The Medical Ethical Committee of the Erasmus Medical Centre (MEC-2009-319) approved this study.

Study participants

Participants (>18 years) of four different yearly national running events in The Netherlands were invited. These running events were the Amgen Singelloop Breda (twice: October 2009 and October 2011), ABN AMRO Marathon Rotterdam (April 2012), and the Lage Landen Marathon Eindhoven (October 2012). The runners could run a variety of distances including the marathon (42,195 km), half marathon (21,095 km), 15 km, 10 km and 5 km runs. Since there was a low turnout on the 15 km distance, these runners were combined with the 10 km group, forming a moderate distance group: short distance (5 km), moderate distance (10 and 15 km), half marathon and marathon. Participants were invited if they subscribed digitally as individual recreational runners at least 4 weeks before the start of the running event and provided a valid email address. Professional runners were excluded. Also, business runners, as in teams of runners from a company, were excluded.

Procedure

Participants received information via email about the study accompanied by a link to an online baseline questionnaire which was developed and used previously.[15,17,20] All participants who returned the baseline questionnaire and agreed with the informed consent, were included in the study and received a follow-up questionnaire one week after the event (and 3, 6, 9 and 12 months after the event). Non-responders received a

reminder within one week. For this manuscript we only use the baseline data and the data of one week after the event.

Baseline determinants

At baseline, runners were asked to complete questions about a) sociodemographic characteristics (e.g. age, gender, height, weight, education, lifestyle (e.g. smoking, alcohol)), b) training related characteristics (e.g. type of training, weekly training frequency, weekly running distance) and c) other running related risk factors, based on the literature (e.g. years of running experience, running terrain, and previous running injuries during the last year).

Categorical determinants with the answer options: always, often, sometimes, rarely, or never, were dichotomized into 'often' (always, often) and 'sometimes' (sometimes, rarely, never), in accordance with a previous study.[17] BMI was calculated based on height and weight and included in the analysis as a continuous variable. The variable 'previous injuries in 12-months preceding the event' was dichotomous (yes/no).

A priori we defined 22 determinants relevant for the analysis: age, gender (male/female), BMI, alcohol use (yes/no), daily smoking (yes/no), education level (high/low), specific feeding supplements (yes/no), injuries in the previous 12 months (yes/no), participation in an organized running group (yes/no), running experience (years), training on firm underground (yes/no), weekly training hours, frequency and kilometers, average running speed, long distance training, interval training (yes/no), stretching before and after the training (yes/no), warming up before and after the training (yes/no) and running distance in the event (5km, 10/15km, half marathon or marathon).

Follow-up measurement

The follow-up questionnaire (one week after the event) obtained information regarding the running event itself (running distance and performance), new running injuries during these events, location of injuries, and pain intensity measured with an 11-point Numeric Rating Scale (NRS).[21,22]

Outcome

The outcome of interest was the presence of new running injuries during the running events as reported during the one-week follow-up. Running injuries were defined as self-reported complaints of muscles, joints, tendons or bones in the lower extremity (hip, groin, thigh, knee, lower leg, ankle, foot and toe) due to running activities by which the running intensity or frequency was reduced, or medical consultation was needed.[7,13,17,23]

Statistical analysis

Descriptive analysis. If participants subscribed to more than one of the running events (e.g. Singelloop 2009 and 2012), we only included the data of the first running event in which the participant took part. We calculated descriptive statistics (frequencies) for baseline characteristics, including means and standard deviations. In case the data did not show a normal distribution, we presented medians and interquartile ranges. We used the Independent Samples T-test to analyze differences between responders and non-responders.

Risk model development. Before developing a multivariate logistic regression model we evaluated multicollinearity between potential determinants; if a correlation between two determinants was ≥ 0.8 only one of the determinants was chosen for the multivariate analyses. First, the multivariate analysis was performed in the total cohort (method Backward Wald, p<0.1 for exclusion). Secondly, we calculated risk models for each distance separately. Results were expressed in Odds Ratios (ORs). In case of missing variables, participants were excluded from the multivariate analysis. We complied with the 1 in 10 rule (one determinant per every 10 injuries) in the analysis, and selected the appropriate number of determinants a priori, based on the literature.[25]

Potential risk predictors. An overview of all 22 determinants is given in Table 1. For the 5km runners we could enter 5 to 6 variables in the regression model. We choose to enter the variables that were found relevant in a previous study (age, previous injury, weekly training distance, interval training and participation in organized running groups).[13] Among 10-15km runners 21 (all except running distance) variables could be entered into the regression analysis. Finally, we included 18 determinants in the analysis of the half marathon group (age, gender, BMI, alcohol use, daily smoking, education level, specific feeding supplements, injuries in the previous 12 months, participation in an organized running group, running experience, training on firm underground, weekly training hours, frequency and kilometers, average running speed, long distance training, interval training). The same determinants were used in the analysis for the marathon runners.

Model performance. Lastly, performance measures of the model were calculated: explained variance (R^2) and the area under the curve (AUC)). The AUC represents the ability of the risk model to distinguish between patients with or without an injury at the 1 week follow-up and ranges from 0.5 (no discrimination) to 1.0 (perfect discrimination).[25]

An AUC ≥ 0.7 is considered good discrimination and an AUC between 0.6 and 0.7 as moderate discrimination. Data were analyzed using the Statistical Package for Social Sciences (SPSS version 23, Inc, Chicago, Illinois).

Results

Participants. In total 17,891 participants received an invitation to participate by email, of which 3,768 runners (21.1%) returned the baseline questionnaire. In total 383 participants ran 5km, 1,189 participants ran 10km, 185 ran 15km, 927 participants ran the half marathon and 1,055 participants the marathon. Added numbers do not match up completely because of some missing data.

Baseline. The mean age of the runners was 42.8 years, with a range from 16–83 years; 60.8% were male and the average BMI was 23.4 (see Table 1). The percentage of males was highest in the marathon group (78.5%) and lowest in the 5km group (23.2%). Also the percentage of runners using food supplements was highest in the marathon group (52.9%) and lowest in the 5km group (8.6%). Almost half of the runners replied with a "yes" when asked whether they had suffered running injuries during the 12 months before the baseline questionnaire.

Follow-up. At the follow up (one week after the event) in total 2,763 runners (73.3%) responded to the follow-up questionnaire (see Figure 1). We found statistically significant differences between responders and non-responders at follow-up for some variables. Non-responders were notably younger, had a higher BMI, ran shorter distances more often and there were more female responders compared to the rest of the group (see table 2). Although statistically significant, the differences between the groups were small.

In total 2,566 participants (92.9%) started and finished, 46 participants did not finish, and 151 persons did not start due to sickness or injuries. We received data on 194 injuries oncurred in 2721 runners between answering the baseline questionnaire and the follow-up (i.e. after the baseline questionnaire but before the event or during the event). Overall, 811 runners (21.5 %) reported one or more running injuries at the follow-up; 5km: 17.5% (67/250), 10-15km: 18.7% (257/981), half marathon: 23.1% (214/708) and marathon: 25.2% (266/762).

Table 1: Characteristics of the running cohorts

Determinants*	5 km N=383	10-15 km N=1374	Half marathon N=927	Marathon N=1055	Total N=3768
Demographic determinants					
Gender: males (%)#	89 (23.5)	695 (50.6)	642 (69.3)	828 (78.5)	2270 (60.2)
Age in years, mean (SD), range #	39.1 (12.4), 16-73	41.8 (11.4), 16-77	43.2 (11.4), 17-75	45 (9.6), 19-83	42.8 (11.2), 16-83
BMI, mean (SD)#	23.8 (3.1)	23.6 (2.6)	23.2 (2.4)	23.1 (2.2)	23.4 (2.5)
Education level, higher education (%)	300 (78.3)	1045 (76.1)	716 (77.2)	795 (75.4)	2857 (76.3)
Daily smoking: yes (%)	291 (76)	60 (4.4)	38 (4.1)	32 (3.0)	161 (4.3)
Alcohol use: yes (%)	29 (7.6)	1152 (83.8)	725 (82.5)	847 (80.3)	3080 (81.7)
Special feeding supplements: yes (%)#	33 (8.6)	163 (11.9)	218 (23.5)	558 (52.9)	979 (26.0)
Previous injury 12 months: yes (%)#	175 (45.7)	536 (45.0%)	520 (56.1)	626 (59.3)	1976 (52.2)
Training related determinants					
Trainings distance, km/week, mean (SD), range #	12 (7), 2-50	20 (11.2), 1-81	31.7 (14.4), 1-87	46.5 (17.6), 1-100	29.5 (18.4) 1-100
Training frequency, times/week, mean (SD) range #	2.3 (0.7), 1-6	2.4 (0.8), 1-12	2.9 (0.9), 1-7	3.7 (1.1), 1-12	2.9 (1.1), 1-12
0-2 (%)	241 (62.9)	768 (55.9)	295 (31.8)	83 (7.9)	
Running speed during training km/hr, mean (SD), range #	8.9 (1.8), 5-16	10 (1.7), 5-25	10.8 (1.4), 5-17	11.0 (1.4), 5-21	10.4 (1.7) 5-25
Running experience, years, median (IQR), range #	2 (1-7), 0-45	4 (2-11), 0-48	5 (3-12), 0-51	8 (4-18), 0-56	5 (2-13) 0-56
0-2 year, n (%)	226 (59.0)	551 (40.1)	207 (22.3)	147 (13.9)	
Hard training underground: often (%) #	308 (80.4)	1184 (86.2)	813 (87.8)	969 (91.8)	3298 (87.5)
Long-distance training: often (%) #	306 (79.9)	1241 (90.3)	864 (93.2)	994 (94.2)	3430 (91.0)
Interval training: often (%) #	120 (31.3)	497 (36.2)	417 (45.0)	441 (41.8)	1484 (39.4)
Warming-up before training: often (%)#	206 (53.8)	651 (47.4)	424 (45.7)	417 (39.5)	1711 (45.4)
Stretching before training: often (%)#	194 (50.7)	700 (50.9)	453 (48.9)	423 (40.1)	1783 (47.3)
Cooling down after training: often (%)#	220 (57.5)	666 (48.5)	385 (41.4)	363 (34.4)	1650 (43.8)
Stretching after training: often (%)#	262 (68.4)	918 (66.8)	577 (62.2)	549 (52.0)	2323 (61.6)
Organized running in groups: yes (%)#	114 (29.8)	458 (33.3)	395 (42.6%)	498 (47.2)	1477 (39.2)
Shoe advice: yes (%) #	279 (72.8)	945 (79.4)	806 (86.9)	965 (91.5)	3177 (84.3)

SD: standard deviation; IQR: interquartile range; BMI: body mass index; kg: kilogram; m: meter; km: kilometers; h: hour

*Cumulating numbers do not match because of incidental missing data. # Significant differences between groups.

Table 2: Characteristic of responders versus non-responders

	Responders T1 N=2763	Non-responders N=1005
Gender, male	1698 (61.5%)	572 (56.9%)*
Age, mean (SD)	43.5 (11.1)	40.8 (11.2)*
BMI, mean (SD)	23.3 (2.4)	23.5 (2.6)*
Running distance*		
5 km	253 (9.2%) #	130 (12.9%)@
10 km	1000 (36.2%)	374 (37.2%)
Half marathon	713 (25.8%)	214 (21.3%)
Marathon	780 (28.2%)	275 (27.4%)

* means statistical significant difference ($p < 0.05$); # = % runners within responders; @ = % runners within non-responders

Risk models

Total cohort. In total 2,369 runners were included in the multivariable analysis, of which 709 (out of 811) had a running injury. We found no correlations between determinants above 69%, so no determinants were removed from multivariable regression analysis. Multivariable regression analysis resulted in a risk model including 4 determinants (see table 3): two of which were risk factors (increasing the risk of an injury): previous injuries (OR 3.7; β 1.30) and running distance during the event (OR 1.3; β 0.27), two others were protective: older age (OR 0.99; β -0.013) and more training kilometers per week (OR 0.99; β 0.012). The Hosmer & Lemeshow test is not significant, indicating a good fit of the model. The overall risk model has an explained variance (Nagelkerke's R^2) of 12%, AUC of 68.4% (66.2–70.6), and it correctly classifies 70% of the runners.

Analyses per running distance. Since the running distance was a significant risk factor we also calculated a risk model per running distance (see table 3). We found a 5km risk model including 4 determinants: age (OR 0.97: β -0.026), previous injury (OR 4.1: β 1.400) and weekly training distance (0.95, β -0.057). Among 10-15km runners we found a 10km risk model including 5 determinants: age (OR 0.98; β -0.018), BMI (1.1; β 0.074), previous injury (OR 3.8; β 1.325), weekly training distance (0.97; β -0.026) and training frequency (OR 1.3; β 0.279) which correctly classified 72.7% of the runners (R^2 = 13.4%). For the half marathon and marathon runners, the regression analysis revealed a model including 2 determinants: previous injuries (OR 3.3; β 1.204 half marathon runners and OR 4.3; β 1.448 in marathon runners) and weekly training distance (OR 0.98; β -0.013 in both risk models).
For all risk models the Hosmer & Lemeshow test was not significant, indicating a good fit and all risk models correctly classify 66-76% of the runners. Furthermore, the AUC for all risk models was moderate.

Discussion

We found an incidence of running injuries between 17.5% (5km) and 25.2% (marathon) depending on the running distance. Running distance during the event appeared to be a significant risk factor for developing running injuries. The distance specific risk models were quite comparable; two factors were present in all risk models: previous injury increased the risk of running injuries and higher number of weekly training kilometers decreased the risk.

Figure 1: Flowchart

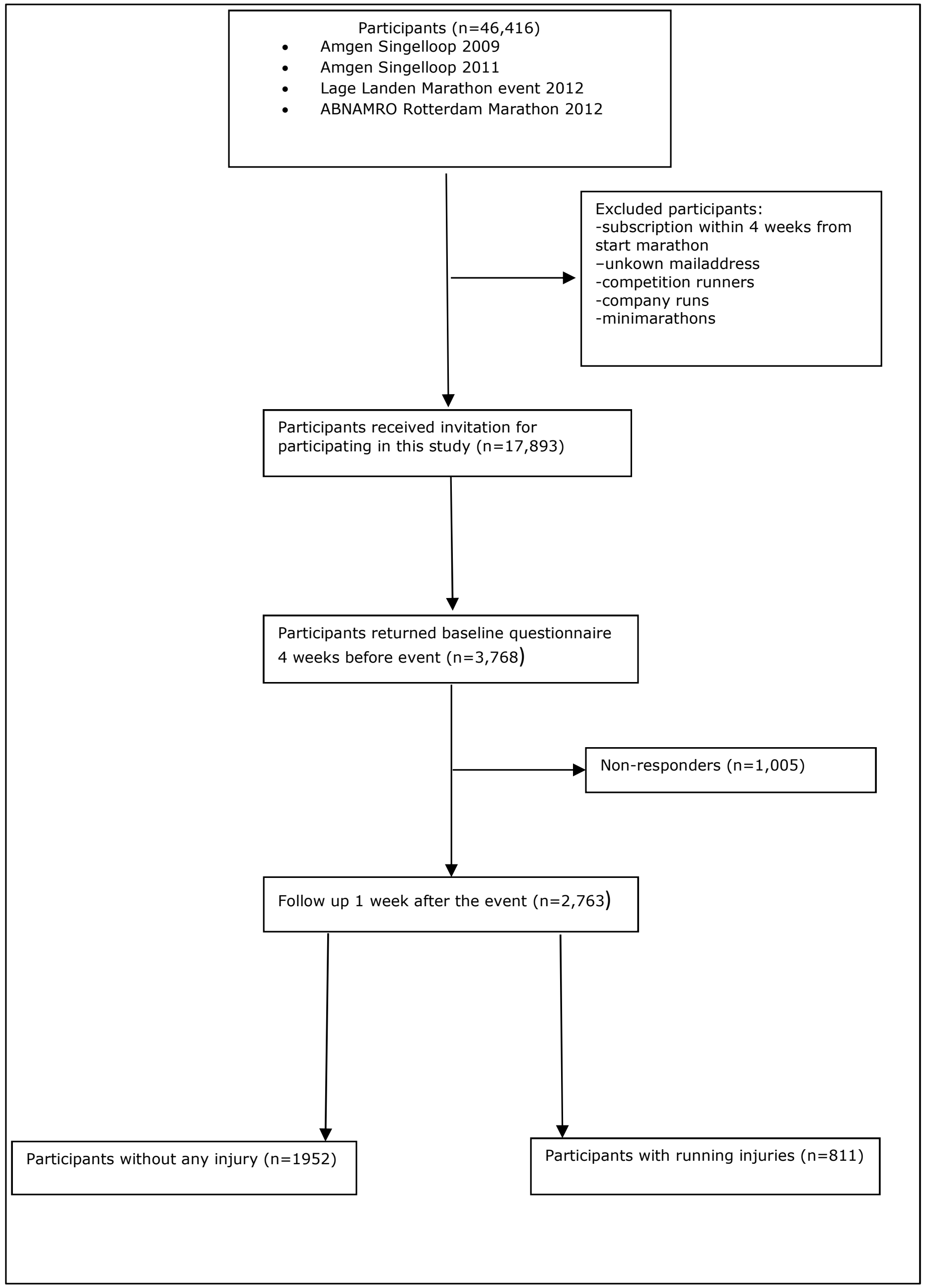

Table 3: Multivariate regression models (backward wald*) for running injuries

Variables	5 km (n = 220, 66 injuries)	10 -15 km (n = 818, 224 injuries)	Half marathon (n = 683, 206 injuries)	Marathon (n = 673, 230 injuries)	Total (n = 2369, 709 injuries)
Running distance during the event (categorical)					1.3 (1.2 – 1.5)
Age (continuous, year)	0.97 (0.95 - 0.99)	0.98 (0.97 - 0.99)			0.99 (0.98 - 1)
Previous injury (yes/no)	4.1 (2.2 - 7.6)	3.8 (2.7 - 5.3)	3.3 (2.3 - 4.8)	4.3 (2.9 - 6.1)	3.7 (3.0 - 4.5)
Weekly training distance (continuous, km)	0.95 (0.9 – 0.99)	0.97 (0.95 - 0.99)	0.98 (0.97 - 1)	0.98 (0.97 – 0.99)	0.99 (0.98 – 1)
BMI		1.1 (1.0 – 1.2)			
Weekly training frequency (continuous, nr)		1.3 (0.99 – 1.7)			
Performance measures					
Nagelkerke R square	15.6%	13.4%	9.6%	13.8%	12.1%
Hosmer -Lemeshow	0.89	0.92	0.12	0.85	0.70
Percentage correctly classified	76.7%	72.2%	70%	66.7%	70.2%
AUC (95% CI)	0.71 (0.64-0.79)	0.70 (0.66-0.73)	0.67 (0.62-0.71)	0.68 (0.64-0.72)	0.68 (0.66-0.71)

Data presented as OR (95% CI) unless otherwise specified; OR > 1.00 is a risk factor; OR < 1.00 is a protective factor; CI, confidence interval; * Exclusion multivariate model p < 0.10.

Comparison with other studies

For the marathon the incidence of running injuries is in line with previous studies among marathon runners.[15,26] This is the first study that developed risk models for running injuries across different running distances in one cohort. Our hypothesis that risk factors for running related injuries vary, depending on the running distances, seems to not be confirmed. We rather found comparable distance specific risk models.

A review described that lower age is a protective factor and older age is associated with an increased risk for running injuries.[16] A possible explanation for our contradictory finding could be that relatively older runners are fitter or better prepared than younger ones. Probably, if they would have had running injuries earlier, they would have stopped their running activities (healthy volunteer bias).[26] Also, knowledge of their body could be better than in younger runners so overuse is less likely to appear.[26] Another explanation could be that peak ground reaction forces (GRF) in older runners seem to be lower than in younger runners and therefore they may be at lower risk. When GRF are higher, loading of joints and muscles is increased and possibly overuse injuries are less likely to appear.[27]

In this study age was only included in the final risk models for the shorter distances and in the overall risk model. Older age was a significant protective factor although odds ratios are small (OR 0.97-0.99) This is due to the fact that age is a continuous variable. This could be clinically meaningless, nevertheless it contributes statistically to the whole risk model.

Gender was not included in any of the risk models; which is in contrast with a recent systematic review,[16] which showed that male gender is a risk factor for running injuries. However, a recent cohort study showed that female recreational runners have a different type of knee loading in comparison to males.[28] If these findings were true, in the runners studied here, we suggest that knee loading is not a meaningful injury risk factor.

Strengths and limitations

Strength of this study is the large population of runners included. Moreover, no previous studies have assessed risk factors in one cohort in four different distances. This study also has some limitations. One of the limitations is the diagnosis of running injuries since we used the self-reported complaints definition.[17,23] There was no physical examination in this study to objectify an injury. Also, participants might have applied the criteria for an injury differently in answering the questions. This could have led to an overestimation of running related injuries because complaints of muscle soreness could be interpreted as an injury according to our definition. On the other hand, there could also be an underestimation while participants did not report any injuries because of the absence of impairments in training or competition and/or medical consultation in regard to the definition from the recent consensus.[29]

Another limitation is that all determinants were obtained by self-reported questionnaires and the validity of the questionnaire is unknown. Therefore, it is possible that we have missed potential relevant risk factors such as psychosocial factors. Self-report studies are inherently biased by the person's feelings at the time they filled out the questionnaire.[30]

Despite these limitations, the results of this study may contribute to the growing body of knowledge of running injuries, especially at other distances than marathon runners only.

Conclusion

We found that risk models for short- and long distance runners did not differ much. Previous injury is the most important generic risk factor for running injuries, as is weekly training distance. To prevent running injuries three risk factors seem to be important: age, previous injuries and weekly training volume. Previous injuries cannot be modified, although it became clear that it is important to prevent running injuries as this factor is a major contributor to the risk models. Runners should pay attention to their weekly training volume, as a higher weekly volume seems to be protective. There might be an optimum weekly training volume (per running distance of the event), but we were unable to assess that. Future research might also consider individual athletes' relative changes in training loads or the training load compared to the distance ran, rather than the absolute load.

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Chapter 6

Moderate discriminative ability of a risk model for knee injuries among recreational runners: a prospective cohort study in The Netherlands

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Submitted

Abstract

Introduction: The aim of this study was to determine risk factors for running-related knee injuries and to develop and internally validate a risk model that estimates the probability for the occurrence of a knee injury in recreational runners during a running event varying from 5 kilometers up to a marathon.

Materials & Methods*:* This observational prospective cohort study included 3,768 participants. Possible risk factors were measured one month before the start of one of four large running events in The Netherlands. Injury information was obtained using a post-race questionnaire one week after each event. The association between potential risk factors and knee injuries was determined using multivariable logistic regression analysis.

Results*:* In total 2,736 (73.3%) participants responded to the post-race questionnaire of which 197 (7.2%) participants reported a new knee injury. The final risk model contained five factors: the combination of a history of injuries in the previous twelve months, longer running distance during the event less training kilometers, lower BMI and shorter running experience. The explained variance of the risk model was 10.7% and the area under the curve was moderate 0.69 (95%CI 0.66–0.72) after internal validation.

Conclusions*:* This prediction model for running related knee injuries contains five risk factors. Before this model can be used in clinical practice, it needs further validation.

Introduction

Running is well-known form of physical activity and is becoming increasingly popular among recreational sports participants [1,2]. Running is one of the most accessible and popular sports activities worldwide[3]. Many people start running because it has several health benefits such as weight reduction and improvements in cardio respiratory fitness and mental health[4]. The majority of these runners are recreational runners[5].

Despite the popularity of running it has some disadvantages also, the occurrence of injuries and other physical impairments[6]. Depending the definition of running-related injuries (RRIs), the type of runner investigated, the observation time and the study design, incidence rates of RRIs vary between 19.4% and 79.3%[5,7,8]. Most RRIs are injuries in lower extremity, predominantly the knee[5,8]. The incidence of knee injuries varies between 7.2% and 50.0%[8]. Although factors for developing RRIs in general have been extensively evaluated in short- and long-distance runners [9-11] there is a lack of evidence in identifying risk factors for specific RRIs such as knee injuries. Only a few studies evaluated risk factors for running related knee injuries[12,13].

General risk factors that are associated with lower extremity RRI in recreational half marathon and marathon runners were less than five years of running experience, frequent interval training, a history of previous injuries and an increased training volume per week[5,8,12,13] . Risk factors for lower extremity injuries in male marathon runners are participating more than six times in a race in the previous twelve months and previous running injuries[9]. In recreational runners conflicting evidence exists for other potential risk factors such as age, height, body mass index (BMI), sex, training distance, running experience, type of shoes, use of orthotics, warming-up and cooling-down strategies[10,13-17].

Specific risk factors for running related knee injuries might differ from risk factors for RRIs in general. A study that investigated risk factors for lower extremity injuries among male marathon runners found that knee injuries were associated with previous running injuries, a running experience of more than fifteen years and a lack of interval training[13]. Because of the high amount of knee injuries within RRIs and lack of knowledge it is important that we understand risk factors for running-related knee injuries in recreational runners in order to be able to prevent these injuries. Therefore, the aim of this study is to determine risk factors for knee injuries in recreational runners and to develop and internally validate a risk model that estimates the probability of obtaining a knee injury in recreational runners.

Methods

Design

This is an observational prospective cohort study in recreational runners in the Netherlands. The Medical Ethical Committee of the Erasmus Medical Centre Rotterdam (MEC-2009-319), the Netherlands, approved the study. The STROBE guidelines and the TRIPOD statement were used to report the study[18].

Participants

Recreational runners who participated in the Amgen Singelloop Breda (October 4, 2009), the Amgen Singelloop Breda (October 2, 2011), the Lage Landen Marathon Eindhoven (October 14, 2012) and the ABN AMRO Marathon Rotterdam (April 15, 2012) were eligible for this study. Runners participated in different distances including the marathon (41.195 kilometers), half marathon (21.095 kilometers), 15, 10 and 5 kilometers (km) runs.

Participants (≥16 years) were included if they were recreational runners, able to read and understand the Dutch language and if they returned both the baseline- and follow-up questionnaire. Exclusion criteria were registration ≤4 weeks prior to the start of the event, no email address available or company runners.

Procedure

One month before the event all participants received an email of the organization with information about the study, an invitation to participate and a link to the online baseline questionnaire. All runners were asked to fill in the baseline questionnaire (T0) before the start of the event. The follow-up questionnaire was sent one week after the event and collected information about the running event and the occurrence of new running injuries. Non-responders received a reminder within one week.

At baseline runners were asked to complete questions about demographic characteristics (age, sex, height, weight and education), training related characteristics (training frequency, training distance, speed during training, type of training, warming-up and cooling-down strategies in the past three months), years of running experience, lifestyle (other sport activities, smoking, alcohol and overall health) and running injuries during the previous twelve months. This baseline questionnaire has been used before (v Middelkoop 2008).

The outcome of interest is the presence of self-reported new knee injuries during the running events as reported at follow-up (i.e. one week after the event). New running-related knee injuries are defined as self-reported symptoms of the knee joint originated during the running event which reduced running intensity or running frequency, or medical consultation for knee pain was needed[5,19,20].

Statistical analysis

Categorical determinants, with the answer options 'always, often, sometimes, rarely or never' were dichotomized into 'often' (always, often) and 'sometimes' (sometimes, rarely, never) conform a previous study[9]. Body mass index (BMI) was calculated based on height and weight.

We selected the appropriate number of determinants according to the 1 to 10 rule (one determinant per ten injuries)[21]. Based on literature we a priori defined 14 determinants relevant for the analysis: sex (male/female), age, BMI, injuries in the previous twelve months (yes/no), running experience (years), weekly training hours, frequency and kilometers, member of a running group, long distance training (often/sometimes), interval training (often/sometimes), warming-up before (often/sometimes), cooling-down after the training (often/sometimes) and running distance during one of the events (5, 10/15, 21 and 42 kilometers)[5,9,12,13].

If runners participated in more running events (e.g., Singelloop 2009 and 2011) we only included the data of the first running event in which the participant took part.

To evaluate selective response between runners that responded to the follow-up questionnaire and runners lost to follow-up, we used the independent samples T-test.

Multicollinearity between potential determinants was evaluated and the linearity assumption was tested. If a correlation between two determinants was ≥0.8 we chose one of the determinants for the multivariable analysis.

We used descriptive statistics for baseline characteristics, frequencies for categorical variables and means and standard deviations (SD). In case data did not show a normal distribution, we calculated medians and interquartile ranges (IQR) for continuous variables. We performed a complete cases analysis.

First, for the univariable regression analysis, we evaluated the association of all the 14 predetermined predictors with the outcome. Next, we performed a multivariable Backward Wald regression analysis (p=0.157 for removal from the model)[18]. A new self-reported knee injury after a running event was the dependent variable.

We present odds ratios (OR) with 95% confidence intervals (CI). Calibration of the final logistic model was done using the Hosmer-Lemeshow goodness-of-fit-test and the

explained variance with the Nagelkerke R^2. A higher p-value for model fit represents a better fit and $p<0.05$ indicates a statistically significant lack of fit[22]. Discrimination of the model was assessed using the area under the curve (AUC) to evaluate how well the model discriminated between participants who had a knee injury from those who were not injured[23]. The AUC ranges from 0.5 (no discrimination) to 1.0 (perfect discrimination). An AUC ≥0.7 is considered as good discrimination, an AUC between 0.6 and 0.7 as moderate discrimination and an AUC <0.6 as poor discrimination[22]. Lastly, we performed internal validation using bootstrap techniques. The final model was bootstrapped (1000 repetitions) to determine overfitting.
Data were analyzed using the Statistical Package for Social Sciences (IBM SPSS version 24, Inc, Chicago, Illinois).

Results

Participants

A total of 17,891 participants received an invitation by email to participate in this study and 3,768 runners (21.1%) returned the baseline questionnaire (figure 1).

Baseline characteristics

Table 1 presents the baseline characteristics of all participants. The mean age was 42.8 (SD 11.2) years. In total 60.2% of the participants were male and the mean BMI was 23.4 (SD 2.5). More than half of the participants had one or more running injuries within the twelve months preceding the baseline questionnaire (52.2%).

Follow-up

In total, 2,763 runners (73.3%) responded to the follow-up questionnaire (figure 1). There were small, but statistically significant differences between responders and non-responders at follow-up. Non-responders were significantly younger, had a higher BMI and ran more often shorter distances in comparison with the responders.
In total 2,566 (93%) participants started and finished their run, 46 (1.2%) participants started but did not finish and 151 (5.5%) participants did not start because of injuries or sickness. Overall 811 runners (29.8%) reported one or more running injuries at follow-up. Of all injured runners, 197 participants (24.3%) reported a knee injury (figure 1).

Table 1: Baseline characteristics

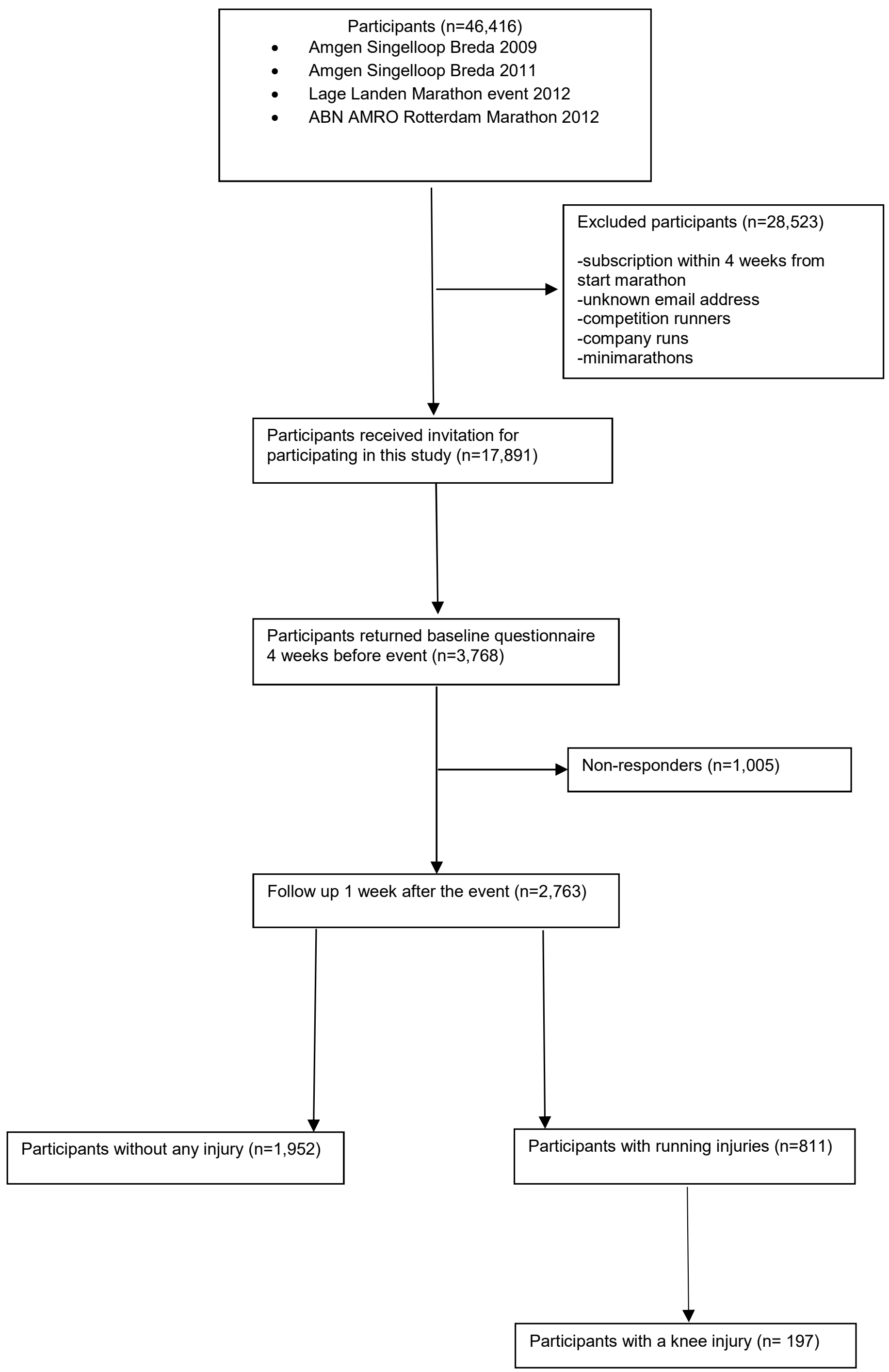
Determinants	Total n =3,768
Demographic determinants	
Sex: males (%)	2,270 (60.2)
Age in years: mean (SD)	42.8 (11.2)
BMI: mean (SD)	23.4 (2.5)
Education level: higher education (%)	2,875 (76.3)
Daily smoking: yes (%)	161 (4.3)
Weekly alcohol use: yes (%)	3,080 (81.7)
Previous injury ≤12 months: yes (%)	1,967 (52.2)
Training-related determinants	
Running experience in years: median (IQR), range	5 (11), 0-56
Training hours, hr/week: mean (SD)	3.5 (2.0)
Training frequency, times/week: mean (SD)	2.9 (1.1)
Training distance, km/week: mean (SD)	29.5 (18.4)
Member of a running group: yes (%)	1477 (39.2)
Running on tartan: often (%)	338 (9.0)
Long-distance training: often (%)	3,430 (91.0)
Interval training: often (%)	1,484 (39.4)
Warming-up before training: often (%)	2,281 (60.5)
Cooling down after training: often (%)	2,650 (69.1)
First running event: yes (%)	481 (12.8)

SD: standard deviation; Higher Education = University; IQR: interquartile range; BMI: body mass index; kg: kilogram; m: meter; km: kilometers; hr: hour.

Risk model

Because of multicollinearity between weekly training hours and weekly training kilometers, we removed the variable weekly training hours from the regression analysis. The final risk model consists of five risk factors: injuries in the previous twelve months, BMI, running distance at the event, running experience and weekly training kilometers (Table 2). Previous injuries and a longer running distance during the event increased the risk of a knee injury, all other factors decreased the risk. The final risk model: (Constant =) 0.28 + (3.43 x previous RRI) + (4.54 running 21km during the event or 2.42 running 42km during the event) + (0.98 x weekly training km) + (0.94 x BMI) + (0.98 x years of running experience).

Figure 1: Flowchart



The risk model has an explained variance (Nagelkerke R^2) of 10.7% and an AUC of 0.70 (95%CI 0.66 – 0.74). The Hosmer-Lemeshow test is not significant (p=0.15), indicating that the model fits the data. After bootstrapping the AUC slightly changed to 0.69 (95%CI 0.66 – 0.72).

Table 2: Univariable and multivariable risk model for knee injuries

Variables	Univariable OR (95% CI)	Multivariable OR (95% CI)
Sex (male)	0.83 (0.57 – 1.23)	
Age (years)	0.99 (0.97 – 1.00)	
BMI (kg/m2)	0.95 (0.88 – 1.03)	0.94 (0.87 – 1.00)
Previous injury ≤ 12 months (yes)	3.43 (2.39 – 4.95)	3.43 (2.29 – 4.93)
Running experience (years)	0.99 (0.84 – 1.18)	0.98 (0.96 – 1.00)
Weekly Training frequency (times per week)	1.09 (0.87 – 1.38)	
Weekly training distance (km)	0.98 (0.96 – 1.0)	0.98 (0.97 – 0.99)
Running group (yes)	0.85 (0.56 – 1.28)	
Long-distance training (often vs sometimes)	1.16 (0.62 – 2.14)	
Interval training (often/sometimes)	0.86 (0.58 – 1.27)	
Warming-up (yes)	0.90 (0.62 - 1.32)	
Cooling-down (yes)	1.15 (0.77 – 1.72)	
Running distance event (5, 10, 21 or 42 km)		
10 km	1.11 (0.61 – 2.03)	1.06 (0.59 – 1.91)
21 km	4.82 (2.41 – 9.65)	4.54 (2.34 – 8.82)
42 km	2.55 (1.24 – 5.27)	2.42 (1.22 – 4.80)
		Performance measures
Constant		0.28
Initial AUC (95% CI)		0.70 (0.66 – 0.74)
Bootstrap AUC (95% CI) Hosmer-Lemeshow		0.66 – 0.72) 0.15
Nagelkerke R^2		10.7%

SD: standard deviation; Higher Education = University; IQR: interquartile range; BMI: body mass index; kg: kilogram; m: meter; km: kilometers; hr: hour.

Discussion

This study developed and internally validated a risk model for running-related knee injuries in recreational runners. The risk model includes five determinants: a history of injuries in the previous twelve months and a longer distance run during an event increase the risk of a running related knee injury. More weekly training kilometers, a higher BMI and a longer running experience decrease the risk of a running related knee injury.

Comparison with other studies

One previous study found a risk model for running related knee injuries[13]. Determinants in this model; interval training, a previous RRI and running experience. Only a previous RRI was included in our risk model. The importance of a history of injuries in the previous twelve months, is supported by previous studies in general RRIs[1,12,24]. While the mechanisms of developing RRIs based on hard evidence are not well known, it could be possible that runners who had an earlier injury, had an inadequate rehabilitation, returned to sports to soon, had insufficient healing process are more likely to get injured. Eventually a new RRI could be developed easier or the previous injury returns. Full recovery seems to be important when a runner suffers an injury and wants to resume or continue running[5,8,9,13].

More training kilometers, longer running experience and higher BMI were considered as protective factors for the occurrence of running-related knee injuries in our study.

A possible explanation for this finding could be "a survival of the fittest phenomenon" where relatively fitter older, more experienced, runners continue running[25,26]. Probably, if they would have had running injuries earlier, they would have stopped their running activities. Also, knowledge of their body could be better than in younger runners so overuse is less likely to appear.

Another possible explanation, more training kilometers per week and a longer running experience have positive effects on the musculoskeletal system[26,27]. A well-trained body with a musculoskeletal system and anatomical sites that are adapted to loading muscles and joints during running could prevent a runner from running injuries. It is known from previous studies that an increased training volume in male runners is a risk factor for running injuries in general, so also overuse injuries can occur when a runner increases the amount of training kilometers per week without a well-structured training previousy[8,12,13].

Another protective factor in the risk model is a higher BMI. This result is supported by another study[28]. They found that a low BMI (<21.7) was a risk for injuries because the participants had extremely low fat and reduced muscle mass levels[28]. Furthermore, they found that the lowest risk for an injury was found among the most aerobically fit trainees who exhibited 'average' weight levels[28]. Nevertheless, in other studies, most often in

novice runners, a high BMI (>26) is often associated with a RRI in general[10,17]. A previous study found a lower BMI in runners who are participating in marathons and half-marathons compared to runners that are participating in shorter distances[5]. It could be possible that running distance is a confounder in this study.

Strengths and limitations

This study focuses on a large number of recreational runners and varying running distances resulting in more generalizable results. Internal validation did hardly change the AUC, meaning that there was no overfitting of the model.

A limitation of this study is that all outcomes and risk factors were self-reported. It should be noted that the definition of injuries used in this study is the same as been used in other studies but slightly differs from a new international consensus on defining an injury[29,30]. Differences in understanding the definition of an injury could also lead to under- or overestimation of the incidence of injuries. Participants could have applied the criteria for an injury differently.

Another limitation is that there could be some selection bias in this study. People with an injury could be more motivated to fill in the follow-up questionnaire compared to runners who did not have an injury. We also noticed that runners who participated in short distance runs responded less frequently to the follow-up questionnaire. It could be possible that these runners more often have no injury compared to runners who participated on longer distances, meaning selective loss to follow-up. Recall bias could be present at follow-up. However, the degree of recall bias is probably not high because the participants received and returned the follow-up questionnaire relatively quickly after the event.

Based on the AUC score, the prediction model can possibly be improved by adding determinants that could have been missed or determinants that are not measured in this study. This could be physical factors, such as running technique, stride length, and type of landing. Factors that are related to knee injuries but we could not measure are, for example, muscle strength and work-related factors[4].

Implications for research and clinical practice

Further research could involve physical factors and results from the physical examination as relevant determinants for running-related knee injuries. The next step for future research is to improve the risk model with appropriate performance and discrimination and externally validate this prediction model in a new large dataset with more determinants that are possibly related to the occurrence of running-related knee injuries[4]. Despite the limitations of this study, the results contribute to the knowledge base and addresses the need for evaluating the risks and risk factors for obtaining a running-related knee injury specifically. The current model cannot be used in clinical practice,

Conclusion

This risk model indicates that the combination of a history of injuries in the previous twelve months, longer distance during the event, less training kilometers, lower BMI and a shorter running experience increase the risk of a running-related knee injury. However, the explained variance is limited and the model needs further validation before these can be used in clinical practice.

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Chapter 7

General discussion

Introduction

A walk in the park shows you how popular running currently is. Recently, there has been an increase in individuals that run for recreational purposes. Also, the number of running groups and running-related sports activities like city runs, obstacle courses and Viking runs increased enormously. The threshold to start running is rather low. Only a small investment in clothes and shoes is needed besides creating time for running. A big advantage of running is that it can be done individually, independent of other people or sports facilities. Although, some runners prefer running in groups which can be more sociable and motivational. Beside all the health benefits that are related to running, previous studies showed that running related injuries (RRIs) often occur.

The incidence of RRIs varies from 20 up to 79% or between 7.7 and 17.8 injuries per 1,000 hours of running[1,2]. Most of these injuries resolve within a few days or weeks without treatment. However, some of these injuries result in healthcare consumption and there is a lack of good prevention strategy. Many studies have been performed, but evidence is not conclusive concerning risk factors for running related injuries. The question is whether relevant (modifiable) risk factors can be identified, and RRI be predicted. To gain answers on this question, this thesis has been performed.

Knowledge in literature on incidence, course and risk factors is inconsistent[3,5]. In chapter 2 we describe the incidence and course of RRIs during one running event in The Netherlands. Generally, the incidence and prevalence of RRIs is high with the knee as the predominant site of injury. In chapters 4 and 5 we presented risk models for RRI injuries in general. Risk models between different types of runners (from 5 km to marathon distances) vary, but one factor is consistent, namely having suffered previous running related injuries increases the risk of future RRIs. Due to the major contribution of knee injuries in RRIs we develop a risk model specifically for knee injuries (see Chapter 6).

In this discussion chapter we compare our research findings with current literature and address limitations. Moreover, we discuss the impact on daily practice and propose fundamental changes in the way future research should be done to determine risk factors for RRI as a next step to develop an injury prevention program.

Incidence, prevalence and site of injuries

The Bress study in chapter 2 was developed to determine incidence, prevalence and course of RRIs during one running event in The Netherlands. We found a high prevalence of RRIs of 46.3% and an average 3 month incidence of 16.3%. This is in line with older[6-8] as well as more recent studies[9,10]. Although there is an increasing body of evidence in regard to incidence and prevalence of RRIs, a systematic review found large differences in injury proportions[4]. Differences in defining a RRI and follow-up period could explain this wide variance. Previous studies show there is a lack of consensus on defining a RRI[11,12]. Therefore, a Delphi study reached consensus on a definition of a RRI[13]. A RRI was defined as; "Running related (training or competition) musculoskeletal pain in the lower limbs that causes a restriction on or stoppage of running (distance, speed, duration, or training) for at least 7 days or 3 consecutive scheduled training sessions, or that requires the runner to consult a physician or other health professional".

Most studies define RRIs as injuries related to running activities, but there still is an enormous variety of definitions due to use of different timeframes. Studies used definitions in which no timeframe was mentioned[6], symptoms had to restrict running activities for at least one day[14-16], or symptoms should be present for one week[17], at least 2 weeks[18,19] or even four weeks[20].

As we started this study before the consensus definition was reached, we used a different definition of RRI. In this thesis a RRI is defined as "self-reported complaints of muscles, joints, tendons, or bones in lower extremity due to running activities. Complaints reduce running intensity or frequency, or injured runners need to have medical consultation". Our definition is in line with the consensus definition although it does not take in to account a minimal number of days (of scheduled training sessions) the injury should be present. Therefore, it is likely that in our study, the number of injuries during an event has been overreported; especially as it is hard to discriminate between some muscle soreness and an injury. Another downside of our definition is the fact that runners had to self-report their injuries. Questions can be raised if runners can accurately self-report RRIs. However, a recent study shows that runners are able to validly report an injury (site) but not the type of injury[21].

In general, we found knee injuries as the dominant site for a RRI and this is in line with other studies[6,22,23]. Nevertheless, we found that the site of injuries differs between short- and long-distance runners. In short-distance runners, knee-, calve- and Achilles Tendon injuries were mostly reported while long-distance runners mostly reported knee, hip- and thigh injuries (Chapter 2). It is not clear why short-distance runners report most injuries in the knee and lower part of the leg and long-distance runners report the knee and upper part of the leg. Short-distance runners are quite often less experienced runners[35] and possibly their connective tissue loading capacity is lower resulting in more reported calve- and Achilles Tendon injuries. We assume that in long-distance runners, during an event, running patterns change more as a result of tiredness and mainly the upper leg and hip region are overloaded. There seems to be a difference in site of injuries related to sex and running experience. Female runners and less experienced runners (5 < years of running) report the knee as the predominant site for injuries, but also the shin (Chapter 2). It is unclear what mechanism might have caused this finding. Do female- and novice runners experience more shin related running injuries or is there some confounding as there is a sex difference in novice runners? Recently more women started running so are these results sex- or running experienced associated? Or is there a "healthy runner bias". For example, if people start running, mostly likely they start with short-distance running. When experiencing injuries, like shin splints, they might stop their running activities or will not increase their running distance to long-distance running. As a result this type of injury is less likely to appear in long-distance runners.

In our studies, runners had to report whether they had an RRI within one week after the event, and about 70% of the runners reported a full recovery of their RRI at 10 days after the event. Often no medical attention was needed. To enable comparing results in RRIs research, it is recommended that researchers and clinicians use the consensus definition in future studies.

Aetiology

The nature of RRIs has a multifactorial origin and researchers should look further than a significant association of one risk factor[1,15]. In the introduction, we therefore presented a model with training-related and non-training related risk factors. A general thought is that RRIs occur when training errors are made due to a disbalance in loading and loading capacity. The assumption is that runners run too often, too hard and too long compared to their capacity and this results in a RRI. For injury prevention it could be important to detect these possible risk factors, or a combination of factors, that are modifiable[15,24]. Next step is to determine the effects of modifying risk factors on the incidence of RRIs. If these factors are causal to the development of RRIs and are successfully modified, the incidence of RRIs is expected to decrease.

Despite all previous research on the aetiology of RRIs it is still unclear which factors show a causal relationship. For instance, is changing dose-exposure responses associated with a change in the incidence of RRIs? In addition, the International Olympic Committee statement recommends to further investigate dose-response relationships in larger prospective cohort studies, to better understand the relationships and interactions between possible modifiable and non-modifiable risk factors[25]. Whenever we understand these interactions, we might know how the incidence of RRIs can be reduced in daily practice by coaches and athletes. A model that has been proposed by Bertselsen (2017) shows the development of a RRI due to interactions between structure-specific load capacity and structure-specific cumulative load per running session (Figure 1)[26]. This framework describes that every runner has a structure-specific load capacity that changes influenced by personal- (such as age, diet, sleep), training-related- (such as; time between training sessions, running experience) and health-related factors (such as; previous running related injuries). The structure-specific cumulative loading per running sessions is a sum of the number of strides and the loading per stride that is influenced by the magnitude of the load (body weight, running speed, terrain) and the distribution of the load (running style, running shoes, surface/terrain and anthropometrics). If the structure-specific cumulative loading per running session is higher than the structure-specific load capacity a RRI can occur.

Risk factors and risk models

Risk factors

In our systematic review, we found moderate quality evidence for 'previous RRIs' as the most important risk factor for RRIs in long-distance runners[27]. In addition, high quality evidence was found for 'a previous musculoskeletal injury not running related' to be a risk factor for RRIs and moderate quality evidence for 'higher BMI', 'higher age', 'male sex', 'having no previous running experience' and 'lower running volume' as risk factors for RRIs in short-distance runners only. A previous RRI as a risk factor for new RRIs is in accordance with current literature[1,10]. Previous reviews presented results without grading the overall quality of the evidence. In regard to this, a potential risk factor can only be a risk factor if the majority of the studies (including minimal 50% of the participants) found the specific risk factor associated with RRI (taking in to account the strength of the association that was found). If reviewers in the past[28,29] would have used this methodology, less risk factors would have been found due to judging the overall evidence.

Previous injuries

The review found 'a previous RRI' or 'a previous musculoskeletal injury not running related', in the year before the start of the study, as a risk factor for new RRIs[16,18,30-32]. A possible explanation could be that as a result of these injuries the structure-specific loading capacity is still decreased. A new RRI is more likely to occur when loading remains the same or increases where capacity is still decreased. Another possibility is that the cause of injury is still present. When running is resumed symptoms arise again because the real cause has not been resolved. Also, a majority of runners continue to run because they probably want to achieve their goals, and do not want to downgrade their running intensity in the middle of a program in preparation for a running event, despite some physical discomfort[33]. Hereby forcing themselves to further unbalance actual loading and current loading capacity.

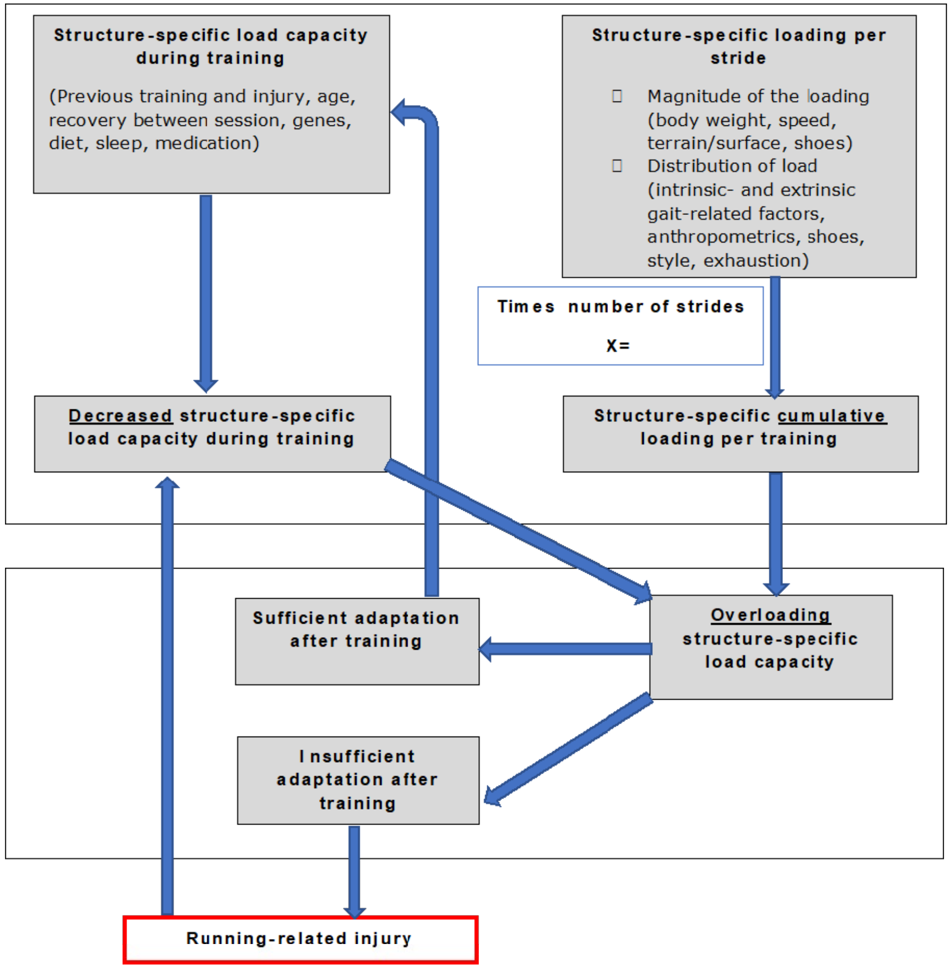

Figure 1; A framework for the aetiology of running-related injuries (a modified version from the original of Bertelsen 2017)

Higher Body Mass Index (BMI)

A higher BMI is found to be a risk factor for RRIs[27] but the association and relationships between BMI, training-related characteristics and RRIs is not fully understood. When starting to run, overweight and obese runners often choose the same kind of running program as runners with a normal weight <25 kg/m^2 [26]. Nevertheless, they are at greater

risk of injury if they ran more than 3 km in the first week of running in comparison with non-obese runners[24]. BMI seems to modify the association between running distance and injury risk in a way that if overweight and non-overweight runners run the same distance the overweight get injured more often. As mentioned before, the exact physiological or biomechanical mechanism seems to be related to a misbalance in loading capacity and functional loading. Is the increase in injury risk a result of a lower structure-specific or generalized loading capacity or an excessive accumulation of biomechanical stress (loading) during running with overweight? The second hypothesis seems to be the most likely one while overweight runners are overweight 24 hours a day and are adapted to living with excessive loads but not with increased excessive load due to running.

Higher age

The relative contribution of higher age in the increased risk of a RRI is only minimal. The odds ratio of age is about 1.02[4]. The role of this non-modifiable and non-training-related factor remains unclear. When getting older, and more experienced over the years, structure-specific loading capacity should increase (see later in this chapter) and the risk of a RRI should decrease if loading is constant. Maybe this is not the case for runners who start running at older age. It might also be possible that there is a certain age from whereon risk increases like in a parabola because physiological changes during aging restrict the body's ability to constantly adapt to continuous loading during trough running a year.

Male sex

We found male sex as a risk factor for RRIs in short-distance runners[34]. The strongest association found was rather low (HR 1.42) as men are more likely to get injured than females[14]. In this study novice runners were included whereby men (57.0%) were much more less previous active than females (38.4%). Also more female runners (38,9%) had no previous injury in regard to men (31.9%). Possibly these factors have biased the results while other studies found no, or only minor effects[4,35].

Lower running volume

We found running volume as a risk factor for RRIs but the literature is not consistent on this variable [6,36]. Two studies including marathon runners found opposite results[6,36]. One study[6] found a lower running volume of less than 40 km per week as a protective factor whereas another[36] found running less than 30 km per week as a risk factor. The interaction with other training-related and non-training-related factors has not been described clearly. Nevertheless, it seems likely that RRIs are of multifactorial origin[1]. It is likely that current unknow interactions of running distance with other factors, for example underground, sex or age, are responsible for the development of RRIs. We found that on average marathon runners are six years older than 5 km runners and that far more male runners (78,5%) ran longer-distance than females (23,5%)[34]. Future research should focus on unravelling these complex interactions.

Novice runners (without previous running experience) versus experienced runners

The majority of studies regarding risk factors for RRIs include short-distance runners[27]. Most of these short-distance studies specifically focused on novice runners[2,4,10,14,24,32,33]. Consequently, the risk factors for short-distance runners identified may actually be more specific to novice runners rather than being related to the running distance profile. Incidence of RRIs is higher in novice runners than in experienced runners[2,33]. As previously discussed in the aetiology of RRIs structure-specific loading capacity plays an important role. It is likely that this structure-specific loading capacity is lower in novice runners in comparison with more experienced runners. Novice runners ran average 20 weeks a year while experienced runners ran 36 weeks a year[2]. As a result, within runners increasing their tissue loading by building up a training program, novice runners could be more at risk to develop a RRI. Also, experienced runners have more experience in increasing and decreasing their training load during a running season and probably have better insight in when to adapt a training program if an injury threatens to arise. Besides previous arguments also a "healthy runners' effect" can exist while healthy runners continue running and injured runners will cease running activities.

Moreover, as discussed before, a previous RRI and a previous injury not running related are the most important risk factors. Ironically, although not impossible, it is less likely a previous RRI will be found as risk factor in novice short-distance runners while about 70% has no or less than a year of running experience[4,10]. If participants did not run in the 12 months before an event/study starts, a previous RRI cannot exist. In our systematic review[27] only half of the short-distance studies[4,16,32] and all studies in long-distance runners[18,30,31] found a previous RRI as a risk factor for RRI. Not surprisingly most studies in short-distance runners were in novice runners and the only study in short-distance runners that not only included novice runners found a previous RRI as a risk factor for RRIs.

Risk models

We developed four risk models for RRIs[34] De performance measures of all models were moderate with an area under the curve (AUC) of about 0.70 and low explained variance (less than 10%). The factors included in the models had low Odd Ratios (between 0.95-1.30), except for previously running related injuries which had ORs varying from 3.3 to 4.3. Also, we found that less than 5 years of running experience and not performing interval training were risk factors for RRIs in half-marathon runners (Chapter 4). In chapter 5 we presented our four risk models for 5km, 10-15km, half-marathon and marathon runners. In the total population, besides a previous RRI injury, running distance during the event was found as a risk factor (OR = 1.30). Older age and higher weekly running distance were found as small protective factors (OR = 0.99) within the model. Within the risk model of 10-15km runners, also higher BMI (OR = 1.10) and higher weekly running distance (OR = 1.30) were found as risk factors.

These results differ from other risk models found in the literature[6,37]. Other studies found that low leg length difference (LLD) was found as risk factor in a general model[37]; running six or more events per year is risk factor for RRI[6] and smoking and higher education level were found as protective factors[6]. None of these factors ended up in our models. A possible explanation is the use of a different kind of regression analyses. A previous study[36] used a poisson regression analyses while another study used a multivariable logistic regression in male runners only[6]. This makes it difficult to compare the results while male and female runners have different personal- and training-related characteristics. We included both males and females and used a multivariable logistic regression analyses to predict the RRI. Basically, the aim of a multivariable regression analysis is to calculate the probability of an event (RRI) with a minimal number of independent variables. This in contrast to association studies in which the association of a specific factor (corrected for confounding) with the outcome is assessed. The aim of this kind of studies is to determine the association of a specific independent variable on RRIs. We should be conscious of this difference while this is of major importance in how potential risk factors enter a model. In association models all known potential confounders should be included in the model. Based on experience, knowledge, and the literature, variables are added to the model or are removed. In current literature mostly the factors that remain in models are presented but there seems to be a lack in presenting a complete overview of variables that entered an analyses and were removed.

In prediction models, variables are stepwise added to or removed from a model in a backward or forward method. Some researchers prefer a method in which the strongest variable is entered first (forward) or choose to remove the least significant variable (backward) where in each step (removing or adding a variable) the fitness of the model is calculated. This process of adding and removing can be done automatically by the statistical package, or by hand based on a clinical theory or rationale.

As mentioned before, multivariable analysis enables us to assess the influence of a combination of independent variables on the dependent variable (RRI). When using this kind of analyses, it is critical to determine whether or not an independent variable is really independent or are related to each other. Therefore, the assumption of multicollinearity should be tested before model building.

Besides the general risk models, a site-specific risk model for knee injuries is presented in chapter 6. Again, a previous running related injury is the most important factor in this model, but the performance measures are rather low. The AUC (95% CI) was 0.70 (0.66-0.74) and the explained variance was 10.7%. This means that only 10.7% of the variance of a RRI can be explained by the risk factors that were analysed. This is in line with the only other known risk model for knee injuries. In that model a previous RRI running experience was a risk factor and interval training a protective factor[6]. Another study also tried to develop a risk model for knee injuries but did not found any statistically significant risk factors[37].

Although risk models are more appropriate for predicting RRIs than single factor studies, they are less valuable when the explained variance is very low and external validation is lacking. All existing risk models are only internally validated and external validation is lacking, implicating that these models are not ready yet to be used in daily practice.

Costs and implications for daily practice

Mostly, injuries do not stop runners in their running activities. About 86% of injured runners continue running despite their injury[2]. Novice runners have a higher healthcare consumption than experienced runners[33]. Limited evidence shows that RRIs can lead to direct and indirect costs[39,40]. The directs costs (healthcare utilization) per RRI are estimated at €57 and the indirect costs (e.g. absenteeism from work) varies between €26,29-€115,75 per RRI[39]. The indirect costs for sudden unset injuries were €33,92 higher than injuries with gradual onset[40].

About 46.3-59.3% of the runners in our population get injured at least once a year[34,41]. In our cohort of about 3700 runners a total of 1976 runners got injured during the previous year. The direct costs of one RRI are 83,22 euro[40], making the total costs within this cohort at least €164.000. Considering that many people are running in the Netherlands[42], the annual national healthcare related costs are high. Also, running has many health benefits as describe before. These beneficial effects seems to be smaller while, due to injuries, runners are not able to run or have to decrease their running activities. To regain these benefits, continue a healthy lifestyle and reduce costs, an evidence based successful injury prevention program aimed at modifiable risk factors could be valuable.

Despite some efforts, unfortunately there is a lack of such a program. As the strongest risk factor is a previous injury, to prevent a new RRI we should prevent the previous RRI, but we can only prevent injuries if we know what the other risk factors are. Therefore, the first step to develop an injury prevention program is to better understand the relations between personal-, training- related and health-related in regard to RRIs. After that, large prospective cohort studies including factors on all dimensions with their interactions are needed.

Limitations

This thesis contains several weaknesses. Some of the questions in the questionnaires we used to collect data in chapter 2, 4, 5 and 6 can have confused participants and we had to make decisions how to interpret the given information. Some runners stated an old injury but reported a pain score within new injuries and vice versa, or reported the existence of an injury but did not score any pain. Several runners developed more than one injury during an event. For example, runners reported knee, thigh and calve injuries after an event. For the analyses the injury with the highest pain score was taken as a primary injury. This could mean that the incidence of RRIs is somewhat underestimated because for analyses the cases (runners) were used and not the reported injuries. On the other hand, overreporting could be present while it could be difficult for runners to discriminate between some muscle soreness and an injury, especially for less experienced runners. During the follow up period, runners reported the course of the original primary injury and existence of a new RRI. It is unclear whether this question was interpreted correctly by runners. If runners reported a certain knee injury as primary injury and at follow up a new injury, we were not able to explore this further. Unfortunately, we were not able to determine whether this was a new injury or a relapse/continuation of the injury before. A previous study concluded that runners are able to validly determine a site of injuries but not the type of injury[21]. To prevent this in future studies, these participants can be contacted by an independent researcher to examine whether these were new injuries or not.

Most important, the questionnaires we used were not developed to measure changing training loads during a running season and with current knowledge these data seem to be of major importance. If data gathering is performed by using a running app, we might be better able to have data on this change. These days most runners have a mobile phone which can be used by automatically sending information about running distance, speed, weekly frequency and volume etcetera. This also would offer a solution to properly measure changes in training loads during a season and related it to the occurrence of injuries (if also reported by this app).

From our total cohort of nearly 4000 participants, the drop out between baseline (about four weeks before the event) and shortly after the event varies from 20% to 35% and between baseline and 12 months even more (about 80%). We found no large differences in responders and non-responders, therefore, bias due to selective non-response or drop-out seems not to be present, however we cannot completely exclude it. Using an app, which can automatically send information, will improve to continue participating in future studies, and reduce the lost-to-follow-up.

Finally, the criteria to classify short- and long-distance runners are arguable especially in the group of half-marathon runners. In this thesis short-distance runners were classified as running a maximum of 19 km per week and a maximum of 10 km per training session. Long-distance runners were classified as running at least 20 km per week and more than 10 km per training session[27]. Within the groups of runners who subscribed to events of 5 km, 10 km or marathon distance this classification will not lead to discussion while it is not likely that short-distance runners run more than 10 km per event and marathon runners will run at least 10 km in most of the training sessions. Although, there could be some long-distance runners that use 10 km events for training purposes. Within the half-marathon runners this is more arguable while during a running season they increase their running volume. It is possible that at the start of a season half-marathon runners are more likely to be classified as short-distance runners while when the season continues, they should be classified as long-distance runners. We acknowledge this is arbitrary but there is no perfect system available to classify short- and long distance runners. Moreover, the conclusions in this thesis would not be different while only the classification of 2 out of 29 studies for short- and long-distance runners was arguable[15,43].

Challenges for future research

One of the most important reasons why there is a lack of evidence is probably because of the absence of large prospective cohort studies covering all potential candidate risk factors. Is it unclear whether we are on the right track in recognizing potential risk factors that we include in our analyses or are there interactions that we are not aware of. We found several risk models for short- and long-distance running but the discriminative value and explained variance of the models was rather low[34,41]. Possibly we missed relevant factors or missed important interactions between the risk factors.

Moreover, questions can be raised if the traditional way of statistical analysis is appropriate for this kind of research. Firstly, most studies use multivariable regression analyses to correct for confounders in single factor associations to find causal relations between factors, but do not develop risk prediction models including predictors on the various levels with their interactions. Also risk models should be externally validated and evaluated on their impact on actual risk reduction. Secondly, the univariable regression analysis is still often used to determine whether a possible risk factor has an association with a RRI. However, it might be more appropriate to select predictors and changes in predictors based on a theoretical model.

Also, it might be valuable to focus more on individual changes in loading during a running season than merely determine averages over a year. This should be assessed in future research. In addition, it seems relevant to assess when RRIs do occur, as they might be related to these individual changes. Loading during a running season is inconsistent due to weather influences, macro- and micro planning and injuries, so there is no stable running volume per week. For example, there are periods of more intensive training as preparation before an event and recovery after an event.

Using these individual changes in training related variables should lead to a better understand of RRI. Practically, this implies two major challenges. Firstly, it is difficult to measure continuous changes in training-related factors, using self-reported questionnaires. Fortunately, there are advances in digital measurements with running apps which enables researchers to more accurate measure changing training-related factors on individual and group level. Secondly, if the consensus definition of a RRI is broadly implemented, it is of major importance whether or not runners are able to reliably determine if they experience a RRI. On the opposite, with such a high incidence, it is not realistic for medical professionals to validate all self-reported RRI. To advance future research, we should consider not only individual risk factors, but their interactions, on running distance/intensity/time/structure-specific load capacity or cumulative loading.

In this thesis (chapters 4 and 5) we state that "differences in associations between injuries and risk factors may be explained by differences in selection criteria, study designs, risk of bias tool and data synthesis methods used". But with the current knowledge, we think this is only partly correct because a crucial aspect is missed. During a running season, the amount of loading (exposure due to running) changes from time to time as a result of micro- and macroplanning. This planning is related to running events in which a runner participates but can also be influenced by work, injuries or season changes. Another important issue is a more solid and uniform description of potential combination of confounders, their interactions, exposures and outcome.

To better understand and solving the riddle of RRIs, we should focus on the dose-response relationships and influencing factors with regard to the occurs of RRIs. Next, hopefully a successful prevention protocol tailored to the risk factors can be developed.

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Chapter 8

Summary

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Summary

Last decade running has become more popular among males and females. Many health benefits have been described, among them physical- and mental loading capacity. Unfortunately also injuries occur as a result of running. In recent years many studies have been performed but the incidence of running related injuries (RRIs) remains high. There seems to be a lack of insight in the causal mechanisms for the development of RRIs and possibilities to reduce or prevent these injuries. Therefore the aim of this thesis is to gain understanding into the incidence, course, risk factors and causal mechanisms for RRIs in recreational runners.

The incidence, prevalence and course of RRIs are described in **chapter 2.** The aim of this study was to describe the incidence, 12-month prevalence, and course of lower extremity injuries that occurred during and after the Amgen Singelloop Breda in 2009.
During a year, every three months, 713 participants completed and returned a questionnaire with information about the course and recovery of the injury and occurrence of new injuries. The incidence of running injuries during the Amgen Singelloop Breda itself was 7.8%; most of these injuries occurred in the calf muscle, thigh, and knee joint. Three-month incidence of injuries during follow-up varied between 13.5% and 16.3%. During the 12-month follow-up period, 277 new running injuries were reported. Runners who ran more than 10 km are more susceptible to injury in comparison with runners who ran short distances (10 km or less). In total, 69.1% of running injuries resolves within 10 days. Running injuries are very common among recreational runners.

The aim of **chapter 3** was to perform a systematic review in risk factors for RRIs in both short-distance (mean running distance 20 km/week and 10 km/session) and long-distance runners (mean running distance >20 km/week and >10 km/session). Electronic databases were searched for articles published up to February 2019. Prospective cohort studies using multivariable analysis for the assessment of individual risk factors or risk models for the occurrence of lower extremity running injuries were included. Two reviewers independently selected studies for eligibility and assessed risk of bias with the Quality in Prognostic Studies tool. The GRADE approach was used to assess the quality of the evidence. A total of 29 studies were included; 17 studies focused on short-distance runners, 11 studies focused on long-distance runners, and 1 study focused on both types of runners. A previous running-related injury was the strongest risk factor for an injury for long-distance runners, with moderate quality evidence. Previous injuries not attributed to running was the strongest risk factor for an injury for short-distance runners, with high-quality evidence. Higher body mass index, higher age, sex (male), having no previous running experience, and lower running volume were strong risk factors, with moderate quality evidence, for short-distance runners. Low-quality evidence was found for all risk models as predictors of running- related injuries among short- and long-distance runners. In conclusion, several risk factors for lower extremity injuries have been identified among short- and long-distance runners, but the quality of evidence for these risk factors for running-related injuries is limited. Running injuries seem to have a multifactorial origin both in short- and long- distance runners.

In **chapter 4** the results are presented of a prospective cohort study in risk factors for RRIs among 943 participants of the Lage Landen Marathon Eindhoven 2012. Sociodemographic- and training related factors as well as lifestyle factors were considered as potential risk factors . The association between potential risk factors and injuries was determined, per running distance separately, using univariate and multivariate logistic regression analysis. In total, 154 respondents sustained a running injury. Among the half-marathon runners, in the univariate model, body mass index ≥ 26 kg/m2, ≤ 5 years of running experience, and not often performing interval training, were significantly associated with running injuries, whereas in the multivariate model only ≤ 5 years of running experience and not often performing interval training on a regular basis were significantly associated with running injuries. Among marathon runners, no multivariate model could be created because of the low number of injuries and participants. This study indicates that interval training on a regular basis may be recommended to marathon runners to reduce the risk of injury.

The prospective cohort study in **chapter 5** found that risk factors for running injuries were not related to running distances. Recreational runners who subscribed for running 5 km, 10 km, half marathon and marathon were invited to participate.
They filled in a base- line questionnaire assessing possible risk factors about 4 weeks before the run and one a week after the run assessing running injuries. Using logistic regression we developed an overall risk model and separate risk models based on the running distance. In total 3,768 runners participated in this study. The overall risk model contained 4 risk factors: previous injuries (OR 3.7) and running distance during the event (OR 1.3) increased the risk of a running injury whereas older age (OR 0.99) and more training kilometers per week (OR 0.99) showed a decrease. Models between short- and long distance runners did not differ significantly. Previous injuries increased the risk of a running injury in all models, while more training kilometers per week decreased this risk.

The aim of **chapter 6** was to determine risk factors for running-related knee injuries and to develop and internally validate a risk model that estimates the probability for the occurrence of a knee injury in recreational runners during a running event varying from 5 kilometers up to a marathon. Injury information was obtained using a post-race questionnaire. The association between potential risk factors and knee injuries was determined using multivariable logistic regression analysis. In total 2,736 (73.3%) participants responded to the post-race questionnaire of which 197 (7.2%) participants reported a new knee injury. The final risk model contained five factors: the combination of a history of injuries in the previous twelve months, longer running distance during the event, less training kilometers, lower BMI and shorter running experience.
The explained variance of the risk model was 10.7% and the area under the curve was moderate 0.69 (95%CI 0.66–0.72) after internal validation.

Finally, **chapter 7** discusses the main findings and limitations of this thesis. Furthermore, on the hand of a multifactorial design implications for future research are given.

Samenvatting

Hardlopen is een populaire sport die veelvuldig beoefend wordt door zowel mannen als vrouwen. Diverse positieve effecten op gezondheid zijn bekend zoals een verbetering van fysieke- en mentale belastbaarheid. Helaas gaat hardlopen ook gepaard met het ontstaan van blessures. De afgelopen jaren is veel onderzoek gedaan maar de incidentie van blessures blijft enorm omhoog waarbij het er op lijkt dat er nog onvoldoende inzicht is in de ontstaansmechanismen en mogelijkheden tot preventie, dan wel verminderen, van het aantal blessures. Het doel van dit proefschrift was daarom inzicht te krijgen in de incidentie, beloop, risicofactoren en ontstaansmechanismen van blessures bij recreatieve hardlopers.

De incidentie, prevalentie en beloop van hardloopblessures zijn beschreven in **hoofdstuk 2.** Het doel van deze studie was inzicht krijgen in de incidentie, prevalentie en beloop van hardloopblessures tijdens de Bredase Singelloop Studie (Bress studie) in 2009. Hierbij werden 713 recreatieve hardlopers 12 maanden gevolgd waarbij iedere 3 maanden een vragenlijst moest worden ingevuld met informatie over het beloop en herstel van de blessure en het ontstaan van eventuele nieuwe blessures. De incidentie van blessures tijdens het evenement was 7.8% en de drie-maanden-incidentie varieerde tussen 13.5%-16.3%. Met name knie-, kuit- en dijbeenblessures waren de meest voorkomende blessures. Tijdens de 12 maanden follow up periode zijn 277 nieuwe hardloopblessures gerapporteerd waarbij hardlopers die meer dan 10 km liepen meer kans hadden op het ontwikkelen van een blessure dan lopers die minder dan 10 km liepen. In totaal 69.1% van de blessures bleek binnen 10 dagen hersteld te zijn. Er kan geconcludeerd worden dat hardloopblessures veelvuldig voorkomen onder recreatieve hardlopers.

Het doel van **hoofdstuk 3** was het uitvoeren van een systematische review naar risicofactoren voor hardloopblessures bij zowel korte- (gemiddelde loopafstand van maximaal 20 km per week en maximaal 10 km per training) als lange afstandslopers (gemiddelde loopafstand van minimaal 20 km per week en minimaal 10 km per training). Elektronische databases zijn doorzocht naar artikelen gepubliceerd tot februari 2019. Prospectieve cohort studies, welke een multivariabele analyse hebben toegepast voor het bepalen van individuele risicofactoren of risicomodellen voor het ontstaan van hardloopblessures in onderste extremiteit, werden geïncludeerd. Twee onafhankelijke reviewers hebben studies geïncludeerd en beoordeeld op risk of bias middels de QUIPS (Quality in Prognostic Studies Tool). Daarnaast is de GRADE approach toegepast om de overall kwaliteit van de evidentie te bepalen. Er werden 29 studies geïncludeerd; 17 studies hadden betrekking op korte afstandslopers en 11 op lange afstandslopers. Een studie had onderzoek gedaan naar zowel korte- als lang afstandslopers. Een eerdere hardloopblessure (gemiddelde bewijslast) is de belangrijkste risicofactor voor het ontstaan van blessures bij lange afstandslopers. Een eerdere blessure die niet gerelateerd is aan hardlopen is de belangrijkste risicofactor (veel bewijslast) bij korte afstandslopers. Een hogere Body Mass Index (BMI), hogere leeftijd, geslacht (man), geen hardloopervaring en relatief laag hardloopvolume per week zijn ook sterke risicofactoren (gemiddelde bewijslast) voor het ontstaan van blessure bij korte afstandslopers. Er is weinig tot geen bewijslast voor specifieke risicomodellen met betrekking tot het ontstaan van hardloopblessures bij korte- en lange afstandslopers. Ofwel, er zijn diverse risicofactoren van hardloopblessures geïdentificeerd maar de sterkte van bewijslast is beperkt. Hardloopblessures lijken een multifactoriële achtergrond hebben.

In **hoofdstuk 4** worden de resultaten gepresenteerd van een prospectief cohort onderzoek naar risicofactoren voor hardloopblessures onder 943 deelnemers aan de Lage Landen Marathon Eindhoven 2012. Sociaal demografische- als training gerelateerde factoren zijn, naast leefstijl gerelateerde factoren, onderzocht als potentiele risicofactoren. De associatie tussen potentiele risicofactoren en hardloopblessures zijn, per loopafstand, geanalyseerd middels univariate- en multivariate logistische regressie analyses. Honderdvierenvijftig lopers rapporteerden een hardloopblessure. Bij de univariate analyses bij halve marathonlopers bleken een BMI ≥ 26 kg/m2, minder dan 5 jaar hardloopervaring en het niet veelvuldig uitvoeren van intervaltraining significant geassocieerd met hardloopblessures. In het multivariate model bleken alleen minder dan 5 jaar hardloopervaring het niet regelmatig uitvoeren van intervaltraining significant geassocieerd. Bij marathonlopers werden geen univariate associaties gevonden en kon, door een laag aantal cases, geen multivariaat model gemaakt worden. Deze studie geeft een mogelijke indicatie dat het regelmatig uitvoeren van een intervaltraining het risico op hardloopblessures zou kunnen verkleinen.

In de prospectieve cohortstudie in **hoofdstuk** 5 werd bepaald dat hardloopblessures niet gerelateerd zijn aan loopafstand. Recreatieve hardlopers welke zich hadden ingeschreven voor het lopen van een afstand van 5 km, 10 km, halve marathon of marathon werden gevraagd deel te nemen aan deze studie. Alle lopers hebben 4 weken voor aanvang, en een week na het evenement een vragenlijst ingevuld met betrekking tot potentiele risicofactoren voor hardloopblessures. Middels logistische regressie zijn risicomodellen, per loopafstand, voor het ontstaan van hardloopblessures ontwikkeld. Uiteindelijk hebben 3768 hardlopers deelgenomen aan deze studie.

Het uiteindelijk risicomodel bestond uit 4 risicofactoren te weten; eerdere blessures (OR 3.7) en loopafstand tijdens het evenement (OR 1.3) verhoogden het risico op blessures en hogere leeftijd (OR 0.99) en een toename van aantal kilometers hardlooptraining per week verlaagden het risico enigszins. Concluderend kan gesteld worden risicomodellen tussen korte- en lange afstandslopers maar minimaal verschillen. In alle modellen verhoogt een eerdere blessure, en verlaagt een hoger aantal trainingskilometers per week, de kans op het ontstaan van een hardloopblessure.

Het doel van **hoofdstuk 6** was het bepalen van risicofactoren voor knieblessures welke gerelateerd waren aan hardlopen. Daarnaast werd een risicomodel ontwikkeld en intern gevalideerd dat de waarschijnlijk moest weergeven van het ontstaan van een knieblessure bij hardlopers welke deelnamen aan verschillende loopevenementen. De loopafstand varieerde hierbij van 5 km loop tot een marathon. Hierbij werd deelnemers gevraagd diverse vragenlijsten in te vullen. De associatie tussen potentiele risicofactoren knieblessures werd bepaald door het uitvoeren van een multivariate regressie analyse. Binnen de groep van 2763 respondenten, welke de post-evenement vragenlijst hadden ingevuld, rapporteerden 197 lopers (7.2%) een nieuwe knieblessure. Er werd 5 factoren opgenomen in het uiteindelijke model; eerdere hardloopblessures in de 12 maanden voorafgaand aan het evenement, grotere loopafstand tijdens het evenement, relatief minder kilometer aan training, lagere BMI en weinig hardloopervaring. De verklaarde variantie van het model was 10.7% en area under the curve 0.69 (95% BI 0.66-0.72).

Tot slot worden in **hoofdstuk 7** de belangrijkste bevindingen en tekortkomingen van dit proefschrift bediscussieerd. Daarnaast worden implicaties voor toekomstig vervolgonderzoek gegeven aan de hand van een multifactorieel model.

Dankwoord

Eindelijk! Het is klaar. Het is af. Het is gedaan. Ik ben op de eindbestemming van deze mooie reis aangekomen. Hoe vaak ik mezelf tegen ben gekomen, ik weet het oprecht niet meer. De eerste vier jaar van mijn reis ben ik nagenoeg alleen maar bezig geweest met data verzamelen en opschonen. Als "Murphy" in de buurt had gewoond, ik had het geloofd. Daarna artikelen schrijven en iedere keer denken, tegen beter weten in, dat de eerste versie toch al best wel goed was. Na het verwerken van de interne feedback de artikelen submitten en "fingers crossed" dat het geaccepteerd zou worden. Mijn eerste artikel was er zo doorheen en toen dacht ik nog "als het zo simpel is zouden meer mensen dit doen". En ja hoor, uiteindelijk bleken andere artikelen toch wat minder snel geaccepteerd te worden……

Dit gevecht is ten einde. Alhoewel "gevecht" geen recht doet aan de mensen die de afgelopen jaren, maanden, weken met echte tegenslag te maken hebben gehad. Dan wordt zo'n promotietraject ook in een ander daglicht geplaatst met alle ellende die er ook gewoon nog is.

Gedurende deze exercitie heb ik diverse mensen leren kennen en kan niet anders dan iedereen bedanken. Ik schijn vrij goed te zijn in het onthouden van details en bewaken van overzicht maar durf niet te stellen dat ik in dit dankwoord geen mensen ben vergeten die de afgelopen 13 jaar een rol hebben gespeeld.

Allereerst uiteraard Wendy. Je was er om gevraagd en ongevraagd advies te geven. Hoe vaak heb je mijn voicemail niet ingesproken, omdat ik het weer eens te druk had om op te nemen, en vroeg je hoe het met me ging? Altijd stond je klaar, of het nu in Breda, Amsterdam of zelfs bij je thuis in Den Bosch was. Al vrij snel had je volgens mij ook al door dat je mij maar beter mijn gang kon laten gaan. Eigen flexibele planning en werkwijze waarbij je wist dat ik me wel zou melden als er weer iets te melden was. Jouw feedback ging vaak gepaard met dat ene belletje om een en ander toch een beetje draaglijker te maken. Zelfs tot de laatste feedback met betrekking tot de discussie. Je bent een fijn mens, oprecht, eerlijk en met het hart op de juiste plek. Ik gun toekomstige promovendi jou als begeleider.

Natuurlijk ook Arianne. We hebben met veel respect menig discussie gevoerd waarbij je ongetwijfeld wel eens hebt gedacht "eigenwijs is ook wijs". Hierbij wetende dat het slimmer was om mij nog maar een keer met mijn hoofd tegen de muur te laten lopen en zelf te ervaren dat er dingen anders moesten? Ook na je verhuizing naar Australië ben je altijd betrokken en beschikbaar geweest om feedback te geven waar nodig. Inmiddels weet ik nu ook wat "Dunglish" is. Dank je wel.

En Bart en Marienke. Als externe promovendus hebben we elkaar fysiek weinig gezien en gesproken, maar op de momenten dat er contact of feedback nodig was stonden jullie klaar om te helpen.

Een dappere studente ben ik ook dank verschuldigd. Anouk Slabbekoorn, jij durfde het aan om als student mee te helpen met het schrijven van een systematic review. Ik weet dat dit je tijdens de studie (en daarna) nog veel tijd heeft gekost maar het eindresultaat mocht er zijn. Maarten van der Worp, ook jij speelde hier een rol in. Jij was natuurlijk al gepromoveerd en wist wat voor berg aan werk er op mij afkwam. Ik ben je dankbaar dat je dat nooit hardop tegen me gezegd hebt…… Zonder jou was de review ook niet geworden zoals het nu is. Merel, jij ook dank voor je bijdrage in het schrijven van een artikel.

Dan zijn er ook nog de kleine dingen die het hem doen. Een enorm cliché maar het is echt. Rob Janssen, toen ik je een presentje bracht voor jouw promotie sprak je woorden met een boodschap die ik niet meer ben vergeten. Iets in de zin van "zorg dat je het afmaakt want het wordt alleen maar meer gewaardeerd als je dit na zo'n lange tijd nog af weet te ronden". Steef Bredeweg kwam ik tegen op weg naar zijn auto bij het VSG congres in Ermelo. Een hele korte woordenwisseling welke altijd is blijven hangen. Jij, "en hoe ver ben je inmiddels?" Ikke, "2 publicaties zijn gedaan en het derde artikel is gesubmit". Jij, "oh dan ben je er bijna". Tot op de dag van vandaag denk ik dat je dit oprecht bedoelde, en niet cynisch omdat je nog wist wat er nog zou komen.

In 2006 ben ik begonnen als docent bij Avans Hogescholen in Breda. Gedurende mijn promotietijd heb ik diverse directieleden zien komen en gaan. Helaas hebben sinds 2021 onze wegen zich gescheiden en gaan we zonder elkaar verder. Toch ben ik Avans Hogescholen veel dank verschuldigd voor de tijd die ik heb mogen vrijmaken om aan mijn onderzoek te werken. Ook in het bijzonder de collega's van de minor wervelkolom en collega Bert Mutsaers waar ik altijd wel even terecht kon om mijn gedachten te verzetten, hart te luchten of een medelotgenoot te zoeken.

Nadat ik al een tijd docent was aan de master opleiding sportfysiotherapie vroeg ik Hans Bult, Nederlands Paramedisch Instituut (NPI), of zij een bijdrage wilden leveren. Ik geloof dat ik nog op dezelfde dag bericht kreeg dat Sylvia van den Heuvel paraat stond.

Ook dank aan de organisaties van de Bredase Singelloop, Marathon Rotterdam en Eindhoven Marathon voor de bereidwilligheid om vragenlijsten uit te kunnen zetten onder hun deelnemers en daarmee de broodnodige data te genereren om dit onderzoek uit te voeren.

Uiteindelijk was voor mij het promoveren alleen maar mogelijk door de stabiele omgeving om mij heen.

Ser, Jan, Peter, wat is er nu mooier dan in het stadion slap ouwehoeren over het spel van PSV of andere nog grotere onzin onder het genot van een biertje. Of nog een keertje sushi eten en een terras pakken. Toch Peter? Helaas heeft de coronacrisis er voor gezorgd dat, met de vriendengroep weer een avondje doen, al weer lang geleden is maar ik hoop dat we snel met aanvulling van Niels, Bas, Willian, Maurice, Tom en Martijn weer een ouderwets avondje kunnen houden.

Een plek die me ook echt aan het hart gaat is natuurlijk PECE Zorg. In 2014 opgericht met Sven en Paul waarbij Niels later is aangesloten. Soms ga ik wat sneller dan gepland, dank voor jullie geduld met mij. En natuurlijk het geweldige team dat er staat. Ik zou inmiddels voor iedereen mijn hand in het vuur steken. Of het nu meubelstuk Mylou betreft of Sanne, Mark, Loek, Tom, Laura, Iva, Aukje, Evelien, Daphne, Lieke, Killian, Frank, Michelle, Nicky, Marloes, Caroline, Karin, Ijfke en Isabelle.

Uiteraard ook de collega's van Fysiosupport, Viasana en Maxima Medisch Centrum. De orthopeden van het gezamenlijke schouderspreekuur Anouk Giesberts, Inge Bonneux en

Henk Koot in Eindhoven of Jur, Ralph, Jesse en Andy in Mill. Het is altijd weer een uitdaging om samen te brainstormen over hoe we onze patiënten en collega's kunnen helpen met hun revalidatietraject. Of een cursus geven voor fysiotherapeuten welke zich verder willen specialiseren.

En wat doe je als je wat spanning van je af wilt gooien? Juist, dan ga je een potje darten. Althans ik wel met het gezelligste team dat je maar kunt bedenken. Menig kastelein of barvrouw zal het daar mee eens zijn. Jan, Dennis, Niels, Don, Robert, Rick, Johan, Rens en Rick. En als we een keer geen competitie hoefden te spelen dan was zwager Don altijd wel bereid om ergens tijd vrij maken om een pijltje te smijten. Voordeel daarvan is dat er dan ook geen vrouwenprogramma op televisie gekeken hoefde te worden.
Een rondje hardlopen werkte ook prima om de batterij leeg te trekken en weer op te laden en anders was daar altijd de Krav Mava familie onder leiding van Willem. Houd vol want het komt echt goed.

Ma en pa, bedankt voor alles wat jullie voor me over hebben gehad. En uiteraard mijn "broertje", zo verschillend maar als het echt nodig is, is een telefoontje genoeg. Daar ben ik van overtuigd. En dat geldt uiteraard ook voor de rest van de familie. Pa, ma, Maarten en Els dank voor alle momenten waarop jullie weer bereid waren om op de kids te passen. En schoonzusje Sandra en de kids Tom en Daan. Als het over " ontstressen" gaat; samen met Maarten en Els zijn de vakanties altijd weer een groot feest.

En, 'last but definitely not least', mijn gezinnetje. In een tijd waarin relaties sneller stuk gaan dan porselein in de kast van een olifant, ben ik gezegend met een lieve, leuke, aardige, begripvolle vrouw. Als ik weer eens een keertje achter mijn laptop zat (of zit) voor werk, mijn promotieonderzoek of er weer even uit moest met vrienden of teamgenoten; nooit was het een probleem en altijd was er de ruimte. Zelfs een congres of stage in het buitenland. Als het moest dan werd het gewoon geregeld, ondanks dat er nog voor 2 kinderen gezorgd moest worden en ze zelf ook een drukke baan heeft in het ziekenhuis. Elkaar de ruimte geven en samen veel leuke dingen doen is het geheim en ik kan het iedereen aanraden! En dan blijven Finn en Sven nog over. Een verademing om die kids te zien opgroeien en de puurheid ervan te zien. Wat maken wij het als volwassenen soms toch onnodig complex! Ik hoop dat we nog lang samen zullen zijn en gelukkig blijven.

Een zin die ik ontelbaar vaak heb gehoord. "Papa is dat voor je artikel". Vanaf nu niet meer……

Curriculum Vitae

Dennis van Poppel werd geboren op 4 november 1978 in Eindhoven. Hij rondde het Atheneum af aan SG. Augustinianum in Eindhoven in 1997 en startte datzelfde jaar met de opleiding Fysiotherapie aan de Hogeschool West-Brabant (inmiddels Avans Hogescholen). Hier studeerde hij met genoegen af op het onderwerp reinnervatie en revascularisatie na een voorste kruisband reconstructie. Doordat hij op dat moment niet het gevoel al klaar te zijn om zijn patiënten goed genoeg te kunnen behandelen is hij in 2001 gestart met de opleiding Gezondheidswetenschappen aan de Universiteit van Maastricht en de opleiding tot sportfysiotherapeut welke hij in 2003 met genoegen heeft afgesloten. Nog niet geheel verzadigd en met het gevoel zich nog verder te willen verdiepen volgde vanaf 2003 de opleiding tot manueel therapeut aan de SOMT in Amersfoort, waar hij in 2007 afstudeerde.

Tijdens de studie manuele therapie ontdekte hij dat het uitleggen aan en het helpen van collega's hem veel plezier gaf waarop hij in 2004 bij de Avans Hogescholen is gaan werken. Hier kwam hij in aanraking met het lectoraat Diagnostiek en startte Dennis zijn onderzoek naar risicofactoren voor hardloopblessures onder leiding van dr. Arianne Verhagen en dr. Wendy Scholten-Peeters in samenwerking met het Erasmus Medisch Centrum.

Ook richtte hij in 2008 zijn eigen scholingsbedrijf Progress Educations van waaruit hij nationaal en internationaal cursussen en lezingen verzorgt voor collega's. Met een aantal vakinhoudelijk sterke collega's heeft hij in 2014 besloten om PECE ZORG op te richten. Een bedrijf dat zich richt op hoog kwalitatieve zorgverlening op het gebied van (sport) fysiotherapie, manuele therapie en later nog aanverwante disciplines zoals geriatrie fysiotherapie en echografie. Hierbij wordt ook nauw samengewerkt met andere disciplines in de zorgketen zoals medische specialisten van het Maxima Medisch Centrum, Catharina Ziekenhuis, Viasana en Radboud MC (orthopeden, neurologen, sportartsen, revalidatieartsen), diëtisten en ergotherapeuten. Binnen PECE ZORG zijn ook twee expertisecentra (Schouder Expertise Centrum en Knie Expertise Centrum) opgezet waarbij verwijzers, collega's en patiënten met vragen terecht kunnen indien de revalidatie niet naar verwachting verloopt.

Nu het promotietraject is afgerond zal hij vanaf 2021 ook betrokken zijn bij het Regionaal Tuchtcollege voor de Zorg te Eindhoven.

Meer informatie over zijn huidige bezigheden is te vinden op www.pece-zorg.nl en www.progress-educations.nl.

PhD Portfolio

Erasmus MC, Department of General Practice

PhD Period: September 2008 – September 2021
Promotor: prof. dr. B.W. Koes
Copromotores: dr. A.P. Verhagen & dr. G.G.M. Scholten-Peeters

	Year	ECTS
Conferences		
Awards		
Best poster presentation MECC congress Physiotherapy on the move Maastricht	2011	
Election as best Sport Physical Therapist of the Netherlands	2013-2015	
Oral presentations		
Sportmedisch Wetenschappelijk jaarcongres Ermelo	2019	2
Symposium van Nederlands Atletiek Unie voor hardlooptrainers in Nijmegen	2014	2
Sportmedisch Wetenschappelijk jaarcongres Ermelo	2013	2
KNGF jaarcongres	2013	2
Sportmedisch Wetenschappelijk jaarcongres Ermelo	2012	2
Symposium van Nederlands Atletiek Unie voor hardlooptrainers in Nijmegen	2011	2
Teaching activities		
Teacher Avans University of applied sciences	2006-2021	240
Teacher master Sports Physical Therapy & upgrade Manual therapy Avans+ & NPI	2008-2018	7
NPI expert Sports Health Care	2018-2021	4
Teacher Progress Educations	2008-2021	148
International internships		
University of Southern California Los Angeles	2018	3
HUG Cressy Santé Swiss Olympic Medical Center Geneva Switzerland	2015	3
Royal National Orthopedic Hospital London	2015	3
Courses		
Epidemiological Research by EPIDM Rolduc (Kerkrade)	2011	4
Peer-review		
Reviewer Journal of Sport Rehabilitation	2020	2
Reviewer Scandinavian Journal of Medicine and Science in Sports	2018-2020	2
Reviewer Journal of Sport and Health Science	2016-2020	2

List of publications

This thesis

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Other publications

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George F Winter, **D. van Poppel.** Is there a correlation between half marathon and marathon injuries? And could intervaltraining hold the key to reducing injury risk? Runningfitnessmag.com july 2015 p.66

J.H.A.M. Mutsaers en **D. van Poppel.** Klinisch redeneren in de fysiotherapeutische praktijk. Physios; jaargang 7; nummer 2, juni 2015

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Nederlands Tijdschrift voor Fysiotherapie, 2007; 117 volume 2, pagina 54-58.