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The association between hip dysfunction and lower limb injuries in long-distance runners: a systematic review

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THE ASSOCIATION BETWEEN HIP DYSFUNCTION AND LOWER LIMB INJURIES IN LONG-DISTANCE RUNNERS: A SYSTEMATIC REVIEW

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Physiotherapy

Johannesburg, 2018

Declaration

Declaration

I Malose Monica Tau declare that this research report titled 'The association between hip dysfunction and lower limb injuries in long-distance runners: a systematic review' is my own work unless otherwise acknowledged and that no assistance was provided from other sources except those allowed. It is being submitted for the Degree of Master of Physiotherapy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



(Signature of candidate)

Date: 30/08/2018

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Abstract

Background

Running is an inexpensive popular sport with growing participation worldwide. Running is generally associated with improved overall health but it also yields a significant risk of sustaining running-related musculoskeletal injuries. The association between hip dysfunction and lower limb injuries sustained in long-distance runners is not clear; therefore, a systematic review to clarify this association was needed. The objective of this review was to assess the association between hip dysfunction and lower limb injuries in long-distance runners.

Method

Studies that included participants who were 18 years of age and older, long-distance runners and injury-free at the time of the study, were included in this systematic review. Runners had to have participated at all levels of performance and be followed up for a period of one month or more. Studies that investigated hip dysfunction as an independent variable were included.

Hip dysfunction entails poor hip muscle strength, poor hip control, excessive or limited range of motion, mal-alignment of the hip, and poor hip-running mechanics, but is not limited to the above-mentioned. Lower limb injuries, which include any non-contact injuries of the lower limb, were considered to be the independent variable in this study. Such injuries needed to have been evaluated by health-care providers. However, lower limb injuries that were reported by the participants in this research project were also included in the study. Furthermore, only prospective and retrospective longitudinal cohort studies were included in this systematic review.

A search strategy using the key words “running”, “hip”, and “lower limb injury” was undertaken. The following databases were searched from inception to June 2017: MEDLINE via PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), ProQuest Health, EBSCO MasterFile Premier, Physiotherapy Evidence Database (PEDro), Science Direct, PROSPERO, SCOPUS and SPORTDiscus, all with full text. Unpublished studies were searched on EBSCO

MasterFile Premier Prospective, and observational, longitudinal cohort studies were included in the systematic review. The methodological quality was assessed using the Joanna Briggs Institute's Critical Appraisal Checklist for Comparable Cohort/ Case Control Studies. A standardised data extraction tool from the Joanna Briggs Institute MAStARI was also used to extract data from the included studies.

Results

Eight studies were included in the systematic review. Seven studies were prospective cohort studies and one study was a retrospective cohort study. One study was a dissertation and the remaining seven studies were peer-reviewed articles. No meta-analysis of findings could be performed on account of the heterogeneity of the studies. As such, the findings were analysed in narrative form.

The main hip dysfunction factor studied in long-distance runners was found to be the hip adduction angle and the hip abduction moment. The hip adduction angle in female long-distance runners was considered to be a risk factor for developing patellofemoral pain ($p=0.007$) and iliotibial band syndrome ($p=0.01$). The active straight leg raise test is one of the tests of the Functional Movement screen test that was found to be predictive of running-related injuries in males ($p=0.01$). Moreover, it was noted that the composite score of the Functional Movement screen test is not predictive of running-related injuries ($p=0.10$).

Conclusion

There were methodological differences between the studies, mainly in terms of defining and measuring running-related injuries. It was found that an increased hip adduction angle in female runners is associated with patellofemoral pain and iliotibial band syndrome. Functional tests such as the active straight leg raise test may possibly be used to screen male athletes for running-related injuries.

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List of abbreviations

RRI	Running-related Injury
PFPS	Patellofemoral pain syndrome
AT	Achilles Tendinopathy
ITBS	Iliotibial band syndrome
ROM	Range of motion
IAAF	International Association of Athletics Federation
WHO	World Health Organization
BMI	Body Mass Index
EMTP	Exertion Medial Tibial Pain
EMG	Electromyography
EMD	Electromechanical Delay
VMO	Vastus Medialis Obliquue
WOMAC	Western Ontario and McMaster Universities Osteoarthritis index
FPPA	Frontal Plane Projection Angle
MSP	Medial Shin Pain
MTSS	Medial Tibial Stress Syndrome
MRI	Magnetic Resonance Imaging
GAG	Glycosaminoglan

Chapter 1: Introduction and scope of this research report

1.1 Introduction

Running is a popular, inexpensive sport with participation in it growing worldwide (van der Worp et al., 2015, Hall et al., 2013). Although running is generally associated with improved overall health, there is a significant risk of sustaining musculoskeletal injuries (Nielson et al., 2013). Injury prevalence amongst runners ranges from 11% to 85%, with the lower extremities being the most commonly injured region (Nielson et al., 2013).

The risk factors of running are either modifiable or non-modifiable. The modifiable risk factors of running are training factors such as over-training and under training. High training volumes, fundamental to the long-distance runner's weekly schedule, have been found to be the most important contributing factor to running injuries (Gabbett, 2016). High training volumes increase the susceptibility of wear-and-tear of the musculoskeletal system, as well as fatigue, which both increase the risk of injury (Rasmussen et al., 2013). Factors such as the type of runner, running experience and running distance have to be taken into account during training (Rasmussen et al., 2013). It is believed that runners with a BMI of 30kg/m^3 are at a higher risk of running-related injuries although the evidence is inconclusive (Kluitenberg et al., 2015; Nielsen et al., 2013). Types of runners are also differently predisposed to running-related injury risk. Ultra-marathon runners are found to be at a higher risk of running-related injuries compared to standard marathon runners, cross-country runners and road long-distance runners (Kluitenberg et al., 2015). Biomechanical factors such as increased knee flexion and ankle dorsiflexion and eversion are believed to increase susceptibility to running-related injuries (Greve et al., 2015).

The non-modifiable risk factors of running are gender and previous injury. There is conflicting evidence about gender being a risk factor for running-related injuries (Nielsen et al., 2013; Rasmussen et al., 2013). Runners with previous running-related injuries are at a higher risk for the recurrence of the same injuries or other running-related injuries (Kluitenberg et al., 2015; Malisoux et al., 2015). Several studies have investigated the hip joint as a cause of lower limb injuries such as iliotibial band syndrome, patellofemoral syndrome and tibial stress fractures. Runners with iliotibial band syndrome

are found to have maximum hip abduction velocity and hip flexion velocity, but their range of motion along the frontal plane of the hip, and their hip-joint coordination have been found to be reduced (Grau et al., 2011). Furthermore, Ferber et al. (2010) compared 35 female runners with iliotibial band syndrome to healthy matched controls and found that the injured runners had greater peak hip adduction relative to the controls.

Two studies, investigating the role of hip dysfunction in tibial stress fractures, showed similar results in terms of runners exhibiting peak hip adduction during running (Milner et al., 2006; Pohl et al., 2008). Dierks et al. (2011) compared 20 recreational runners, who experienced patellofemoral pain syndrome after a prolonged run, to 20 uninjured matched controls and found that the injured runners experienced a significant reduction in their hip abduction muscle strength. These studies have shown that hip dysfunction may increase the risk of sustaining running-related injuries.

The identification of risk factors is a crucial step, which precedes measures aiming to reduce the risk of injury through, for example, improving the running gait technique and introducing rehabilitation programmes aimed at addressing muscle weaknesses that are known to be associated with injury (Finch, 2011). Various systematic reviews on the prevention or predictions of running injuries have been conducted. The determinants found included the type of runner; the track or field, and the length of the run , namely short distance, medium distance, or long distance (Videbaek et al., 2015), the training habits (Nielsen et al., 2013), foot wear (Perkins et al., 2014), gender differences (van der Worp et al., 2015), and lower limb alignment (Carvalho et al., 2011).

However, no systematic reviews were found on hip dysfunction as a predictor of running-related injuries in long-distance runners and, therefore, the purpose of this review is to assess the association between hip dysfunction and lower limb injuries in long-distance runners. This systematic review of the literature will generate Level 1 evidence on the association between hip dysfunction and lower limb injuries in runners and may possibly enable health-care workers, coaches and trainers involved with long-distance runners to identify athletes at risk of injury on account of hip dysfunction specifically.

1.2 Problem statement

Running-related injuries can be debilitating for long-distance runners and contribute largely to loss of training time and to limit participation in competitions (Kluitenburg et al., 2015; Alonso et al., 2012). The hip joint is alleged to be one of the contributing factors to the occurrence of lower limb running-related injuries in long-distance runners. The kinetic chain model and studies on the kinetic chain during running verify the anatomical link between proximal and distal structures in running (Karandikar & Vargas, 2011). The relationship between hip dysfunction and lower limb injuries has been studied predominantly in an injured population of runners by means of cross-sectional studies (Noehren et al., 2012). Prospective and longitudinal studies examining the association between hip dysfunction and running-related injuries in long-distance runners have also been completed, but to date there is no systematic review of the above-mentioned (Beard, 2015; Noehren et al., 2012; Eskofier et al., 2012). Currently there is a lack of conclusive evidence regarding the association between hip dysfunction and lower limb injuries in long-distance runners. The knowledge of the association between hip dysfunction and lower limb injuries in long-distance runners could possibly contribute to injury prevention and rehabilitation programmes. Injury- prevention programmes rely mostly on etiological knowledge of injuries for effective outcomes (Finch, 2011).

1.3 Systematic review question

Which factors, specifically related to hip dysfunction, are predictive of lower limb injuries in long-distance runners?

1.4 Systematic review aim

The aim of this review was to determine the factors specifically related to hip dysfunction, which are predictive of lower limb injuries in long-distance runners.

1.5 Systematic review objectives

The objective of this review was to assess the association between hip dysfunction and lower limb injuries in long distance runners.

1.6 Significance of the systematic review

The precise relationship between hip dysfunction and lower limb injuries in long-distance runners is crucial because it may contribute to the pool of knowledge needed to formulate effective injury-prevention and rehabilitation programmes. The evidence may also point to specific populations of long-distance runners at risk of sustaining running-related injuries. The results from this study will inform future research directions, as the gap in the literature will be highlighted.

Chapter 2: Literature review

2.1 Introduction

Running is a common sport and leisure activity among people of all races and ages (Hall et al., 2013). The world's most recognised South African races are the Comrades Marathon and Old Mutual's Two Oceans Marathon. The Comrades Marathon is an ultra-marathon traditionally held in Kwa-Zulu Natal Province between Pietermaritzburg and the city of Durban (Naidoo, 2016), while the Two Oceans Marathon is an ultra-marathon race held in the Western Cape Province starting from Newlands and following a circular route back to the campus of the University of Cape Town (Two Oceans Marathon, 2018). The 2017 Comrades route was confirmed to be 86.73km and 20 000 runners participated in the race (Naidoo, 2016).

The reasons for participating in running and particularly in the Comrades Marathon are fivefold. Firstly, runners feel a need to achieve personal goals; secondly, runners feel the need to explore new running trails while being competitive at the same time; thirdly, runners value spending time together with family away from home; fourthly, running renders the opportunity for socialising, and lastly, the runners are able to commit to something (Kruger & Saayman, 2013).

Runners are classified as recreational runners, novices, short-distance runners, middle-distance runners, marathon runners, ultra-marathon runners or cross-country runners (Kluitenberg et al., 2015).

Long-distance runners are classified as runners running a distance longer than 32 km per week (Macera, cited in Van Middelkoop, 2008). These runners are susceptible to patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome, plantar fasciitis and Achilles tendinopathy (Lopes et al., 2012) [1]. The prevalence, incidence and risk factors of each are pivotal in understanding the impact that these injuries have on runners (Brukner & Khan, 2012)

[1]. These running-related injuries will be elaborated on in the literature review.

The normal biomechanics of long-distance running is significantly different from the biomechanics of walking and sprinting (Brukner & Khan, 2012). The normal and abnormal running biomechanics will be explained to indicate how running-related injuries can develop in the presence of abnormality.

Runners with patellofemoral pain, iliotibial band syndrome and medial tibial stress syndrome have altered hip biomechanics (Becker et al., 2017; Noehren et al., 2014; Noehren et al., 2007,). Reiman (2009) proposes that the relationship between running-related injuries and proximal factors could be due to proximal to distal or distal to proximal factors such as the hip.

The literature review explores the relationship between hip dysfunction and the lower limb by including the epidemiology of running, a description of the risk factors associated with running and the most common running-related injuries. The role of the hip in running-related injuries and the biomechanical link between the hip and the lower limb will also be explored more in detail. The description of how the anatomy and biomechanics of the hip could possibly lead to running-related injuries will be elaborated on. In order to know the adverse effects of movement, the following will be referred to; abnormal anatomy and biomechanics of the hip, why lower limb injuries can occur irrespective of other factors and the normal anatomy of the hip and biomechanics of hip movements.. Normal and deviations of running biomechanics will be elaborated on, with the aim of exploring possible connections with the hip under the heading 'biomechanical link between the hip and lower limb' as well as with running-related injuries. The literature review will then be summarised.

2.2 Search strategy of literature review

A search strategy using the key words "running", "hip", and "lower limb injury" was undertaken. The following databases were searched: MEDLINE via PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), ProQuest Health, EBSCO MasterFile Premier, Physiotherapy Evidence Database (PEDro), Science Direct, PROSPERO, SCOPUS and SPORTDiscus, all with full text.

2.3 The benefits of running

Several studies have shown that running yields health benefits such as preventing obesity, dyslipidaemia, hypertension, osteoarthritis, type-2 diabetes, benign prostate hypertrophy, respiratory diseases, cancer and disabilities (Lavie et al., 2015). Running improves one's quality of life irrespective of the classification of the runner (Lee et al., 2015). Runners have a decreased cardiovascular mortality of 30% to 40% when compared to persons who do not run, and a longer life expectancy of three years irrespective of the running experience (Lee et. al., 2015). Being physically inactive is a threat to one's physical and mental health (Lavie et al., 2015).

The American Heart Association recommends a dose of 150 minutes of moderate exercise or 75 minutes of vigorous physical exercise per week for sufficient cardiovascular health (The American Heart Association, 2017). Schnohr et al. (2014a) suggests that jogging for approximately one to two hours every week is associated with decreased mortality. Light joggers have been found to have the lowest mortality risk compared to moderate and strenuous joggers. Light joggers are defined as runners who run at a slow or average pace at roughly five miles per hour, running for less than 2.5 hours in a week (Schnohr et al., 2014b). Starting to run even at a later stage in life yields cardiovascular benefits to runners compared to persons who have not assumed running (Lavie et al., 2015; Lee et al., 2014). The benefits of running far outweigh the risk of an inactive lifestyle.

2.4 Definitions of running-related injuries

There are various definitions of running-related injuries as researchers either develop their own definitions or adapt those that already exist (Yamato et al., 2016). Lun et al. (2004, p.577) describes a running-related injury as "any musculoskeletal symptom of the lower limb that requires a reduction in or stoppage of normal training". Ramskov et al. (2013, p.409) describes a running-related injury as "any self-reported, running-related musculoskeletal pain of the lower extremities or back causing restriction of running for at least one week". Hespanhol and Lopes, (2016, p.1138) describes a running-related injury as "an injury that occurs due to musculoskeletal pain in the last two weeks that causes a runner to miss at least one training session". These differences pose a challenge when analysing and comparing results.

Thirty-eight expert researchers on running injuries participated in a study to develop a consensus definition of "a running-related injury" in recreational runners. The Delphi method was used and 80.7% of the experts agreed that a running-related injury should be defined as "running-related training or competition, a musculoskeletal pain in the lower quarter that causes a restriction or stoppage of running (distance, speed, duration or training). The stoppage time or restriction should last for at least seven days or three consecutive scheduled training sessions. The injury could be one that requires the runner to consult a physician or other health professional" (Yamato et al., 2016; Timpka et al., 2014). The three key words to define an injury were phrased as "time loss", "medical attention" and "all complaints" (Yamato et al., 2016).

Progress in injury surveillance studies depends partly on a uniform definition of running-related injuries in runners (Timpka et al., 2014). The author discovered that several studies disregard the time lost in participating in running when defining running-related injuries (Timpka et al., 2014). Timpka et al. (2014) suggests that studies in which running-related injuries are self-reported would benefit by including the time lost through the injury.

According to the Delphi study, it is recommended that the definition for running-related injuries should include "time loss", "medical attention" and "all complaints" (Yamato et al., 2016) to foster uniformity when analysing and comparing studies. This is a recommendation and still leaves the responsibility of developing running-related injury definitions in the hands of respective researchers.

2.5 Epidemiology

2.5.1 Incidence and prevalence of running-related injuries

Varying methodological procedures and differences in defining "a running-related injury" (RRI) have contributed to the range of reported incidence and prevalence results (van der Worp et al., 2015; Nielsen et al., 2013). Reporting the incidence and prevalence of running-related injuries in a population of similar demographic attributes gives a more realistic picture of the high occurrence of running-related injuries (Videbaek et al., 2015). Incidence and prevalence will be discussed under the

following subheadings: recreational runner; novice runner; middle-distance runner; marathon runner; ultra-marathon runner and the cross-country runner.

2.5.2 Recreational runners

Recreational runners are runners who run for reasons other than formal competitiveness and usually run as a hobby. These runners usually participate in short races not longer than 10 km (Kluitenberg et al., 2015). Recreational runners running longer distances of 15 to 21 km are more susceptible to running-related injuries than those who run shorter distances of five to 10 km (van Poppel et al., 2014). This is most likely due to a more stringent fitness requirement to run longer races, and a lack of proper training regimes required in order to run longer races.

The incidence and prevalence of injury of recreational runners during the Amgen Singelloop Breda in the Netherlands was 7.8 per 1000 hours of running and 18.8% respectively (van Poppel et al., 2014). In a systematic review study conducted in Denmark recreational runners sustained an incidence rate of 7.7 (95% CI 6.9-8.7) per 1000 hours of running (Videbaek et al., 2015). Hespanhol et al. (2016) conducted a prospective study on 200 recreational runners with a follow-up for a period of 12 weeks. Of the 200 runners, 30% developed new running-related injuries and 28% experienced a recurrence of injury. van Poppel et al. (2014) also conducted a prospective study in which the majority of the injuries were located in the knees (30%), calves (13.9%), hips (12.7%), shins (10.8%) and Achilles tendons (11.4%). Kluitenberg et al. (2015) also established that most running injuries are located in the knee (26.3%).

2.5.3 Novice runners

Novice runners are new to running and do not have any running experience (Kluitenberg et al., 2015). As a result, the incidence of running injuries in novice runners is particularly high (Videbaek et al., 2015). In a systematic review conducted in Denmark, the incidence rate of running injuries was 17.8 (95% CI 16.7-19.1) per 1000 hours of running exposure. Kluitenberg et al. (2015) reported a prevalence of 10.9% of running-related injuries (Videbaek et al., 2015). The majority of the running-

related injuries were found to occur in the knees (38.4%), calves (20%), Achilles tendons (13%) and the shins (13%) (Kluitenberg et al., 2015; Buist et al., 2010).

2.5.4. Middle-distance runners

Middle distance runners are runners who run distances of between 800 and 3 000 m at a time (Kluitenberg et al., 2015). There is a lack of evidence on the incidence and prevalence of middle-distance runners globally. In a systematic review completed in the Netherlands, Kluitenberg et al. (2015) investigated injuries that required medical attention during a running event and found that middle-distance runners experience a prevalence of 12.8% (95% CI 7.0-22.3) of running-related injuries. Furthermore, when studies that examined the time-loss injuries for over a year were pooled, the prevalence was 63% (95% CI 41.4-81.6) (Kluitenberg et al., 2015).

The Daegu International Association of Athletics Federation (IAAF) Championships is an athletic event that takes place in South Korea and athletes from all over the world compete in it (iaaf.org/home). In an attempt to determine the incidence of new injuries affecting middle-distance runners, the 1 851 participating athletes of this tournament were asked to report any injuries to the attending medical staff. It was found that 24% of the runners had sustained running-related injuries during the championship. The main injuries sustained by these middle-distance runners were Achilles tendinopathy, patellofemoral knee pain, iliotibial band syndrome and stress fractures (Edouard et al., 2013).

2.5.5 Marathon runners

Kluitenberg et al. (2015) describes marathon runners as runners who participate in marathons. Marathons are races that are a standard 42.195 km long, while half marathons are 21.0975 km long (IAAF, 2009). There is limited evidence on a global scale of the prevalence of injuries in marathon runners. The incidence of running-related injuries in marathon runners ranges from 16% to 92.4% (van Middelkop et al., 2008; van Gent et al., 2007; Walter et al., 1989) cited in Rasmussen et al., 2013 p. 118. The incidence over a period of four months for marathon runners from a South African Athletic

club was recorded at 0.67 injuries per 1000 km (Hendricks & Phillips, 2013). This incidence rate was less when compared to that reported in other studies (Hendricks & Phillips, 2013). This difference could have been due to the small sample size. The majority of the injuries were located in the knee (20%), calf (18%) and lower back (18%) (Hendricks & Phillips, 2013; Ogwumike & Adeniyi, 2013). The majority of running-related injuries located in the knee in the case of marathon runners was supported by Chang et al. (2012), who reported 29% of injuries that were located in the knee.

2.5.6 Ultra-marathon runners

Ultra-marathons are races that are longer than the standard distance of a marathon which is 42,195 km. The annual incidence of running-related injuries in ultra-marathon runners ranges from 52 to 65% (Hoffman & Krishman, 2014). There is limited evidence concerning the prevalence of ultra-marathon runners globally. It was found that more experienced ultra-marathon runners are at a higher risk of suffering running-related injuries than less experienced runners ($p=0.001$) (Malliaropoulos et al., 2015). Experienced runners run for longer distances, have a longer history of previous injuries, are at a higher risk of an inadequate recovery period owing to participation in numerous races and have a tendency to ignore minor injuries, which may later lead to injuries that are more serious (Malliaropoulos et al., 2015). The main running-related injuries reported in ultra-marathon races is lower back pain (42.5%) and knee pain (40%) (Malliaropoulos et al., 2015). However, in a study of 1 212 ultra-marathon runners, the incidence of injuries located in the knee was the highest at 24%, followed by injuries in the iliotibial band (15.8%), calf (13.1%), back (12.4%) and hamstrings (11.8%) (Hoffman & Krishman, 2014).

2.5.7 Cross-country runners

Cross-country races require that the runners should run under different environmental conditions. Runners compete against each other individually and in teams (Central Gauteng Athletics, 2007). In a study conducted in Indianapolis, women cross-country runners had a higher rate of injury that was 1.25 times higher than that of males (95% CI= 1.05, 1.50) (Kerr et al., 2016). The incidence of injury in cross-country male runners is 4.66/1000 athletic exposure time as opposed to that for females of

5.85/1000 (Kerr et al., 2016). The injuries sustained were found to be mainly due to overuse (Kerr et al., 2016). There is limited evidence on the prevalence of injury in cross-country runners globally. The most common injuries experienced by cross-country runners are located in the lower leg (30.3%), knee (22.5%), ankle (16.2%), upper leg (9.0%), foot (8.1%) and hip/pelvis (5.7%) (Kluitenberg et al., 2015). Most of the injuries sustained by cross-country runners are classified as overuse injuries followed by muscle strains (Kerr et al., 2016).

2.6 Risk factors associated with running

2.6.1 Training factors

Overtraining or undertraining can make a runner more susceptible to injuries. Rasmussen et al. (2013) found that training for distance running over less than 30 km increases the risk of running-related injuries in marathon runners. In a prospective study, Malisoux et al. (2015) reported that recreational runners who run for less than two hours per week (Hazard ratio = 3.29: 95% CI = 2.27: 4.79) and who have less than two training sessions per week (hazard ratio = 2.41: 95% CI – 1.71: 3.42) are at a higher risk of sustaining injuries.

Runners who increase their running distance weekly by more than 30% are prone to running-related injuries compared to those who increase their distance by less than 10% weekly (95% CI: 0.96 – 2.66, p=0.07) (Nielsen et al., 2013). Similarly Kluitenberg et al. (2016) reported that an increase in training intensity is associated with an increased risk of running-related injuries (HR 1, 29; 95% CI 1.18 -1.41).

2.6.2 Types of runners

Runners are classified according to the distance they cover, as well as the experience they have acquired. van Poppel et al. (2014) found that recreational, full marathon runners (42.195km) and half-marathon runners (21.095) tend to sustain injuries at different rates during competition. The half-marathon runners have the highest incidence rate, 131 injuries per 1 000 hours of running compared to the full marathon runners with 66 injuries per 1000 hours of running. In a similar study, ultra-

marathon runners were found to have the highest proportion of injuries compared to standard marathon runners, cross- country runners and road long-distance runners (10km -42.195km) (Kluitenberg et al., 2015). Recreational runners who run for less than two hours per week (Hazard ratio = 3.29: 95% CI = 2.27: 4.79) and have less than two training sessions per week (hazard ratio = 2.41: 95% CI – 1.71: 3.42) are at a higher risk of sustaining injuries (Malisoux et al., 2014).

2.6.3 Biomechanical factors

Abnormal running biomechanics may be linked to running-related injuries (Napier et al., 2015). Biomechanical factors noted to increase the susceptibility of a runner to sustain ankle injuries are an increased knee flexion and ankle dorsiflexion and eversion (Greve et al., 2015). In addition, Dudley et al. (2017) found that in runners with an increased peak ankle eversion, peak external knee adduction moment and velocity was a risk factor for sustaining running-related injuries. Furthermore, runners who developed running-related injuries did not exhibit any differences in hip kinetics and kinematics (Dudley et al., 2017).

There is limited evidence to support the assumption that navicular drop and a low tubercle sulcus angle are risk factors for ankle injuries in runners (van der Worp et al., 2015). Napier et al. (2015) found that some biomechanical factors such as a faulty foot strike, peak vertical impact, step length, step frequency, and ground reaction time are modifiable in re-training programmes. The biomechanical risk factors will be elaborated on in more detail under the hip dysfunction section of each running related injury.

2.6.4 Gender

The association between gender and running-related injuries is still debatable and requires more controlled quality studies. The anatomical and physiological differences between males and females account for the differing proportions of injuries reported in runners of a similar status (Alenzi et al., 2014). In comparison to males, females present with greater knee valgus angles during functional tasks such as running, single leg squats, single leg landing and cutting manoeuvres (Alenezi et al., 2014). In a systematic review on the influence of gender differences on running-related injuries,

women showed less of a risk of developing running-related injuries than men. The risk factors for men and women were also found to differ (van der Worp et al., 2015). Women were found to have a higher risk of developing medial tibial stress syndrome (RR 1.71, 95% CI 1.15-2.54, p= 0.008) than males. In contrast, other studies have found no association between gender and the risk of running-related injuries (Hespanhol et al., 2014; Nielsen et al., 2013; Rasmussen et al., 2013).

2.6.5 Previous injury

Injuries in running are common and athletes need to be rehabilitated to restore them to their optimum health. Insufficient or no rehabilitation can put an athlete at risk of new injuries or of a recurrence of a former injury. There is evidence to support the fact that athletes with previous running-related injuries are at a higher risk of sustaining the same injuries that they experienced before, or of other running-related injuries (Kluitenberg et al., 2015; Malisoux et al., 2015; Hespanhol et al., 2014; Saraggioto et al., 2014; Hespanhol et al., 2013).

Previously injured athletes have a higher risk of injury has been supported by van Poppel et al. (2016), who reported that 60% of recreational marathon runners included in their study had sustained running-related injuries 12 months prior to the study. Similar results were found for cross-country runners who experienced exercise-related leg pain a month prior to the cross-country season (Bennette et al., 2012). Previous injuries not related to running were also found to be associated to a certain extent with a greater risk of sustaining running-related injuries although the association was not reported as statistically significant (Nielsen et al., 2013). However, Nielsen et al. (2013) and Newman et al. (2013) reported that the association between previous running-related injuries and new running injuries was not statistically significant.

2.7 Most common running-related injuries

The main running-related injuries are muscular in origin with the knee being mostly affected (Hespanhol et al., 2013; Rammussen et al., 2013; Hendricks and Phillips, 2013 ; Chang et al., 2012) followed by the foot, ankle (Rammussen et al., 2013; Tonoli et al., 2010) and lastly, the calf (Hendricks and Phillips, 2013). In a systematic review investigating the leading musculoskeletal running-related

injuries, Lopes et al. (2012) identified medial tibial stress syndrome (MTSS), Achilles tendinopathy, plantar fasciitis, patellofemoral pain syndrome (PFPS) and iliotibial band syndrome (ITBS), as the main types of running-related injuries (Lopes et al., 2011).

2.7.1 Medial tibial stress syndrome

2.7.1.1 Introduction

Medial tibial stress syndrome, also called medial tibial traction periostitis (Brukner & Khan, 2012), is a running-related injury resulting from overuse. The global incidence of medial tibial stress syndrome is 13.6% to 20.0% and its prevalence 9.5% (Lopes et al., 2012).

2.7.1.2 Symptoms and clinical presentation

Medial tibial stress syndrome presents as pain and tenderness on the medial surface of the tibia which decreases with activity and increases with rest. The symptoms usually occur during or after an unusual increase in activity such as running longer distances than usual and a sudden increase or heightened intensity in training frequency (Matcuk et al, 2016).

2.7.1.3 Pathophysiology and mechanism of injury

The condition of medial tibial stress syndrome involves tibial periostitis, as well as oedema and micro trauma of the cortical bone. However the cortical bone oedema response does not always occur. Medial tibial stress syndrome occurs when there is a traction force on the periosteum, a connective tissue layer, which covers the external surface of the bones. The traction force is caused by the muscles, which are attached to the medial surface of the tibia, namely to the soleus and flexor digitorum longus muscles (Brown, 2016). The traction force of these muscles increases as the muscular contraction increases during activities such as running and cycling. The traction force causes damage to the cortical bone, resulting in oedema and micro cracks in the bone. The micro cracks are caused by an abnormally high or repetitive load (Matcuk et al., 2016), resulting in inflammation of the

periosteum (Franklyn & Oakes, 2015). This causes bone resorption to occur faster than bone replacement, thus causing pain and dysfunction (Matcuk et al., 2016).

2.7.1.4 Risk factors associated with medial tibial stress syndrome

One of the main intrinsic risk factors for medial tibial stress syndrome in runners is gender. As opposed to their counterparts, women are at a higher risk of medial tibial stress syndrome (Newman et al., 2013; Winkelmann et al., 2015). The reason women are at a higher risk is thought to be because of the biomechanical differences that exist between males and females (Newman et al., 2013). A higher body mass index (BMI) is associated with a higher risk of medial stress syndrome (Reiking et al., 2017, Winkelmann et al., 2015; Newman et al., 2013). However biomechanical factors such as the muscle strength of the ankle invertors, evertors and dorsiflexors, the Q-angle, and the tibial varum, are not, significant risk factors for medial tibial stress syndrome (Reiking et al., 2017).

Intrinsic physical factors in the lower limb that could increase the risk of medial tibial stress syndrome were investigated prospectively in collegiate athletes (Hubbard et al., 2009). The independent variables included the range of motion of the ankle, the isometric strength of the ankle and foot muscles, the tibial varum and the navicular drop. The results of the study indicated that a higher range of motion of plantar flexion ($p=0.004$) in conjunction with a history of medial tibial stress syndrome ($p=0.0001$), is a significant risk factor in medial tibial stress syndrome (Hubbard et al., 2009).
Hubbard et al. (2009) reported insignificant findings on the association between navicular drop and medial tibial stress syndrome. However, in the study of Bennette et al. (2012), runners with an increased navicular drop of >10mm were at a higher risk of developing medial exercise-related leg pain than those who had a navicular drop of <10mm (Reinking et al., 2017; Bennette et al., 2012).

In the study by Becker et al. (2017), participants diagnosed with medial tibial stress syndrome displayed a larger varus angle of the tibia in the standing position ($p=.002$), less range of motion of dorsiflexion ($p=.002$), increased rear foot eversion when measured at the heel-off phase ($p<.001$), and eversion that lasted longer than that of matched healthy controls during walking. The measures in the study by Becker et al. (2017) may be associated with the possibility of developing medial tibial stress syndrome (Becker et al., 2017). These results are contrary to the results of the study by Winkelmann

et al. (2015). According to Winkelmann et al. (2015), the main risk factors in medial tibial stress syndrome are an increased range of motion of the plantar flexion, an increased BMI and an increased navicular drop. Reinking et al. (2017) supported the significance of these risk factors in a more recent systematic review with meta-analysis.

2.7.1.5 Hip dysfunction in medial tibial stress syndrome

In a prospective study aimed to find the role of the muscular strength of the hip in the development of exertion medial tibial pain (EMTP), female physical education students underwent isokinetic tests of their hip muscles. The results of the study indicated that poor hip abduction concentric strength (work $p=0.010$ and power $p=0.045$) is a risk factor for the development of exertional medial tibial pain in women (Verrelst et al., 2014; Mucha et al. 2017).

In a systematic review with meta-analysis, Hamstra-Write et al. (2015) reported that a greater external rotation range of motion ($p<0.001$) of the hip is indicative of an increased risk of medial tibial stress syndrome. The investigators in the study also recommended that future research should include high quality prospective studies for investigating risk factors associated with medial tibial stress syndrome which are currently lacking (Hamstra – Wright et al., 2015).

Hip kinematics is linked to medial shin pain in runners. Loudon and Reiman, (2012) conducted a case control study to investigate running kinematics in runners with a history of medial shin pain (MSP). The runners with a history of medial shin pain experienced a higher frontal plane pelvic tilt ($p= 0.002$, effect size = 0.55) and peak hip internal rotation ($p= 0.004$, effect size =0.51) as opposed to their matched controls (Loudon & Reiman, 2012).

2.7.1.6 Conclusion on medial tibial stress syndrome

Medial tibial stress syndrome has been linked with several risk factors. A history of medial tibial stress syndrome (Hubbard et al., 2009), a higher BMI (Reiking et al., 2017), and range of motion of plantor flexion (Hubbard et al., 2009), and women have a higher risk of medial tibial stress syndrome (Newman et al., 2013; Winkelmann et al., 2015). Hip dysfunction factors associated with the risk of

medial tibial stress syndrome are a poor hip abduction concentric strength (Verrelst et al., 2014; Mucha et al. 2017) and a greater external rotation range of motion of the hip (Hamstra – Wright et al., 2015). Runners with a history of medial tibial stress syndrome present with a higher frontal pelvic tilt and peak hip internal rotation compared to matched controls (Loudon & Reiman, 2012).

2.7.2 Patellofemoral pain syndrome

2.7.2.1 Introduction

Patellofemoral pain is one of the common overuse injuries experienced by runners (Lopes et al., 2012). Patellofemoral pain syndrome is a complex condition with multiple causes that are still under investigation. The risk of patellofemoral pain is higher in females than in males (Myer et al., 2010; Boling et al., 2009). In the United Kingdom, the annual prevalence of patellofemoral pain in the general population of females is 29.9% and 15.5% in males (Dey et al., 2016). Patellofemoral pain is one of the main running-related injuries in ultra-marathon runners with a global prevalence ranging from 7.4% to 15% (Lopes et al., 2012; Scheer and Murray et al., 2011;). In Belgium the incidence of patellofemoral pain in amateur runners during a six week period was reportedly 42.9% (Thijs et al., 2007).

2.7.2.2 Symptoms and clinical presentation

The patient with patellofemoral pain may present with the symptom of pain, which is aggravated by loading of the patellofemoral joint, for example, with activities such as running, climbing stairs and other weight-bearing activities. Tenderness around the patellar and knee instability are also usually experienced. There may also be signs of swelling around the patellar, the crepitus, under the patellar, and tenderness on the lateral, medial or inferior sides of the patellar. In addition, patients may also present with atrophy of the vastus medialis obliquue muscle and an impaired contraction quality of the muscle (Brukner & Khan et al., 2012**).**

2.7.2.3 Pathophysiology and mechanism of injury

Patellofemoral pain syndrome refers to pain found on the anterior side of the knee joint located posterior to the patellar and excludes any intra-articular pathologies (Brukner & Khan, 2012). Patients rarely present with the same symptoms, thus contributing to the complexity of the aetiology of the pain. An increase in the pain with loading of the joint is usually the main symptom. The intensity of the pain experienced, as well as limitations in the physical activity levels, also differs from patient to patient (Lieb & Perry, 1968; Witvrouw et al., 2005). Pain is felt in the innervated structures of the knee joint such as the patellar ligament, the infrapatellar fat pad, the subchondral bone, the quadriceps tendon, the synovium, the patellar tendon, and the medial and lateral retinaculum (Sanchis-Alfonso et al., 2001).

Perspectives on the biomechanical and tissue homeostasis are two theories that Petersen et al. (2013) and Dye, (2005) postulate to explain the cause of anterior knee pain. The biomechanical perspective attributes anterior knee pain to innervated structures; tightness of the hamstrings or the iliotibial band, the maltracking of the patellar, the dynamics of the knee valgus, pronated feet, increased rear foot eversion, and the muscular imbalance of the vastus lateralis or medialis muscles (Petersen et al., 2013). The tissue homeostasis perspective states that overload of the patellofemoral joint causes pathophysiological processes that result in patellofemoral pain (Dye, 2005). The overloading of the patellofemoral joint by a single excessive load or through chronic repetitive loading can cause tissue injury and thus a loss of normal tissue homeostasis (Dye, 2005).

Pathophysiological processes that may result in patellofemoral pain include the following; inflammation of tissues such as the synovial lining and the fat pad, knee oedema and effusion, causing increased intra-osseous pressure, and increased metabolic processes of the patellar bone on account of direct trauma, the presence of cytokines, and the changed pH level of the tissues that have been damaged. When these processes occur, there is a loss of tissue homeostasis (Dye, 2005). Currently, there is no evidence supporting the fact that the infra-patellar fat pad and the retinaculum can cause a nociceptive output that causes patellofemoral joint pain (Witvrouw et al., 2014)

Patellofemoral pain has also been associated with functional activities, such as squatting, climbing stairs, running downhill and jumping, that cause increased loading in the patellofemoral joint (Brukner & Khan, 2012).

The following factors have been identified as contributing to patellofemoral pain: mechanical factors such as direct trauma to the patellofemoral joint; knee movements that cause high intrinsic forces that are compressive and tensile in nature; abnormal knee alignment, which may predispose the joint to abnormal forces and the impingement of structures inside the knee joint, and increased pressure inside the knee joint (Petersen et al., 2013; Brukner & Khan, 2012).

2.7.2.4 Risk factors associated with patellofemoral pain

Factors that increase load in the patellofemoral joint are capable of increasing the risk of patellofemoral pain. These risk factors are either extrinsic or intrinsic (Brukner & Khan, 2012). Extrinsic risk factors of patellofemoral pain are factors such as training at a higher intensity by performing exercises, such as squats, lunges, stair climbing, running at an increased speed, as well as running by bounding, that increase load in the patellofemoral joint and direct trauma to the patellofemoral joint (Brunkner & Khan, 2012).

Intrinsic factors increasing the risk of patellofemoral pain are an increased knee valgus, femoral internal rotation, tibial rotation, subtalar pronation, impingement of structures, increased pressure inside the knee joint, and poor flexibility (Brukner & Khan, 2012; Halabchi et al., 2013). Females may be at a higher risk of patellofemoral pain than males (Boling et al., 2009). Lower limb flexibility and strength were investigated in a group of athletes with and without patellofemoral pain. Flexibility of the hamstring, quadriceps and gastrocnemius were tested with a gravity inclinometer. The athletes with patellofemoral pain experienced less hip extensor torque ($p=0.031$), less ankle dorsiflexion ($p=0.038$), and less hamstring flexibility ($p=0.006$). Quadriceps flexibility was not associated with patellofemoral pain (Silva et al., 2016). This was contrary to an earlier study of Witvrouw et al. (2000) in which a low level of flexibility of the quadriceps muscle was reported as a risk factor of patellofemoral pain.

The difference in the results of these studies could have been attributed to the different methods of measuring the flexibility of the quadriceps muscles. Witvrouw et al. (2000) measured quadriceps flexibility with the participants in a prone position, with the opposite lower limb positioned on the floor at 90 degrees of hip flexion. The involved limb was passively flexed and the angle measured with a goniometer. Silva et al. (2016), on the other hand, measured quadriceps flexibility with the participants in a prone position and the hips in a neutral position. The involved knee was passively flexed and the angle measured with an inclinometer.

There is inconclusive evidence supporting weak knee extension as a risk factor for patellofemoral pain syndrome (Esculier et al., 2013). According to a systematic review, which included seven prospective studies (Thijs et al., 2011; Boiling et al., 2009 & 2010; Van Tiggelen 2009; Witvrouw 2000 Duvigneaud, 2008; Milgrom, 1991), weak knee extension strength is linked with an increased risk of patellofemoral pain syndrome (Lankhorst et al., 2012). Lankhorst et al. (2012) states that this systematic review did not follow the Rule of Ten, which suggests that "at least ten individuals with patellofemoral pain should have been included for each predictive variable considered" (Concato et al., 1995). One of the limiting factors in this study was the study method employed in each of the included studies. Since the included studies did not adhere to the Rule of Ten, there was a risk of a Type I error occurring whereby variables would be presented as predictive factors, whereas this was not the case (Lankhorst et al., 2012).

The results of the systematic review of Lankhorst et al. (2012) were supported by two studies in which the reduced muscular strength of the knee flexors was found to be associated with an increased risk of patellofemoral pain (Boling et al., 2009; Pappas & Wong-Tom, 2012). There is currently no evidence supporting increased or decreased Q-angle (Witvrouw et al., 2014), abnormal patellofemoral joint (Witvrouw et al., 2014), and rear foot eversion (Barton et al., 2012) as risk factors of patellofemoral pain.

The factors associated with patellofemoral pain are numerous and warrant further research. To understand these risk factors, prospective and larger control studies on patellofemoral pain need to be conducted (Powers et al., 2011).

2.7.2.5 Hip dysfunction in patellofemoral pain

Athletes who are rear foot strikers and who experience patellofemoral pain, have been found to present with altered gluteus medius activation (Esculier et al., 2015) and altered electromechanical delay of the vastus medialis obliquues and lateralis (Chen et al., 2012). Similar results were found in the study of Rogers et al. (2017), who investigated the activity of the gluteus muscles in participants with patellofemoral pain. These authors conducted a systematic review of literature published from inception up until September 2011. They found an association between patellofemoral pain and the activation and contraction time of the gluteus medius muscles during certain functional activities such as running, stair climbing and descent (Rogers et al., 2017).

Wilson et al. (2012) found that females tend to have a higher peak activation level of the gluteus maximus muscles (40%) ($p=0.028$) than males. This is hypothesised to be a contributing factor to the development of patellofemoral pain in that it causes fatigue and thereby abnormal kinematics in the hip and knee joints when running. This would also cause increased retro- patellar stress, which contributes to anterior knee pain (Wilson et al., 2012).

Participants with patellofemoral pain have more medial femoral rotation ($p=.037$) at 45, 30, 15 and at zero degrees of a double-leg squat. The largest difference noted was at zero degrees in females with patellofemoral pain (12.2 degrees) versus the 6.2 degrees presenting in their controls (Souza et al., 2014). It was concluded that altered patellofemoral joint kinematics is more inclined to be due to femur rotation than to patellar rotation (Souza et al., 2014).

Female runners with patellofemoral pain present with a larger peak hip adduction, internal rotation, increased strength in the external rotators, as well as increased internal rotation of the shank (Noehren et al., 2012; Willy et al., 2011). Female runners with patellofemoral pain exhibit greater peak hip adduction when compared to matched male runners with patellofemoral pain (Rathleff et al., 2014; Willy et al., 2011; Nakagawa et al., 2012; Boling et al., 2009). The difference between the results for the male and female runners is proposed to be due to the biomechanical differences between the two genders (Rathleff et al., 2014; Willy et al, 2011).

Athletes with patellofemoral pain exhibit more knee abduction in running (Korsgaard et al., 2015). An association between knee abduction and eccentric hip abduction strength was found in the group with patellofemoral pain (-1.80; 95% CI -3.59; -0,009).

2.7.2.6 Conclusion on patellofemoral pain

Patellofemoral pain may result from multiple causes (Myer et al., 2010). There are numerous factors associated with patellofemoral pain that still warrant further research (Powers, 2011). Patellofemoral pain is associated with functional activities, knee joint movements and abnormal knee joint alignment that increase loading in the patellofemoral joint (Brukner & Khan, 2012; Petersen et al., 2013).

Runners with patellofemoral pain present with altered gluteus medius activation (Esculier et al., 2015; Rogers et al., 2017) and altered electromechanical delay of the vastus medialis oblique and lateralis (Chen et al., 2012). Female runners with patellofemoral pain present with a greater medial femoral rotation (Souza et al., 2014), peak hip adduction, hip internal rotation, and strength of hip external rotation (Noehren et al., 2012; Willy et al., 2011).

2.7.3 Iliotibial band syndrome

2.7.3.1 Introduction

Iliotibial band syndrome is an overuse injury characterised by pain on the lateral side of the knee supposedly caused by friction of the iliotibial band against the femoral lateral epicondyle (Brukner & Khan, 2012). The iliotibial band is a band or fascia found on the lateral side of the thigh. The fascia originates proximally from the gluteus maximus and the tensor fascia lata muscles and forms the iliotibial band. The iliotibial band then inserts by means of five insertions onto the Gerdy's tubercle (no. 1)), the capsular-osseous of the tibia (no. 2), the lateral epicondyle (no. 3), the linea aspera on the lateral femoral diaphysis (no. 4), and the lateral patellofemoral retinacular complex (no. 5) (refer to Figure 3 [Flato et al., 2017]). The iliotibial band functions to extend, laterally rotate and abduct the hip. (Flato et al., 2017)

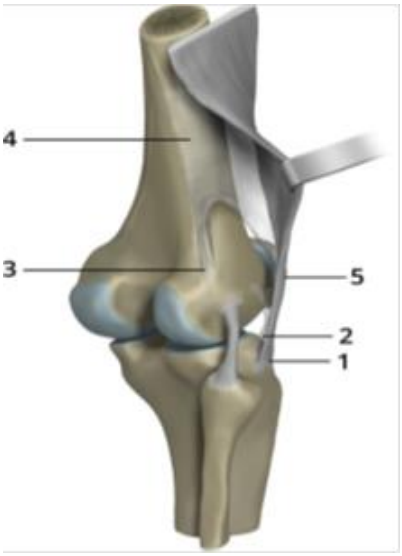


Figure 1 Illustration of the distal iliotibial band insertion (Flato et al., 2014)

2.7.3.2 Symptoms and clinical presentation

The main indicator of iliotibial band syndrome is pain occurring on the lateral side of the knee, mainly with flexion. The pain increases with running and knee flexion/extension movements. On palpation, there is tenderness on the lateral side of the knee over the lateral femoral epicondyle (Brukner & Khan, 2012).

2.7.3.3 Pathophysiology and mechanism of injury

The global incidence of iliotibial band syndrome in runners ranges from 1.8 to 9.1 %, and the prevalence is 10.5% (Lopes et al., 2012). The development of iliotibial band syndrome is believed to be due to one of two or both theories, described in Baker et al. (2016). The first theory is the compression and enthesopathy theory and the second is the friction and impingement theory.

The compression and enthesopathy theory refutes the friction and impingement theory, which states that the iliotibial band syndrome is caused by lateral femoral epicondyle and iliotibial tract friction that occurs during flexion and extension of the knee joint (Brukner & Khan, 2012; Baker et al., 2016). It is further believed that this friction causes inflammation of the iliotibial tract and impingement of

the lateral bursae. According to the compression and enthesopathy theory, there is no bursa cushioning the iliotibial band laterally but instead there is connective tissue, and also fat, that is found between the iliotibial band and the lateral femoral epicondyle. Iliotibial band syndrome is believed to be caused through the compression of these tissues. The compression and enthesopathy theory states that iliotibial band syndrome is associated with poor posterior and lateral hip muscle function during deceleration in running, more specifically the eccentric and isometric muscle function (Baker et al., 2016).

2.7.3.4 Risk factors associated with iliotibial band syndrome

The extrinsic risk factors associated with iliotibial band syndrome are training habits such as downhill running, a fast increase in running intensity and the type of shoe worn (Saikia & Tepe, 2013). The intrinsic factors are Q-angle, faulty alignment of the lower limb, weakness of the gluteus maximus and minus muscles, increased internal rotation of the knee in the stance phase of running, tightness of the iliotibial band, as well as the size of the lateral femoral epicondyle (Saikia & Tepe, 2013).

A systematic review to determine the biomechanical risk factors of iliotibial syndrome was conducted and it was reported that peak hip adduction and peak knee internal rotation could be associated with the risk of developing iliotibial band syndrome (Adarem & Louw, 2015). Ferber et al. (2010) conducted a study on female runners with a prior diagnosis of iliotibial band syndrome to investigate knee kinematics as opposed to their matched controls. The participants underwent an instrumented gait analysis on a 25m runway at a speed of 3.65m/s and stepped on a force plate in its centre. The participants with a history of iliotibial band syndrome exhibited greater peak internal rotation angle of the knee ($p=.03$) (Ferber et al., 2010; Louw et al., 2014).

2.7.3.5 Hip dysfunction and iliotibial band syndrome

Foch et al. (2013) investigated running biomechanics in female runners with previous iliotibial band syndrome. Female runners with previous iliotibial band syndrome exhibited less hip adduction through the stance phase as opposed to their controls. Similar results of less hip adduction were reported in a prospective study (Noehren et al., 2007). Similarly, Grau et al. (2011) reported that runners with iliotibial band syndrome had less hip adduction prior to the push-off phase and less

maximum velocity of hip flexion and knee flexion as opposed to their matched controls. The results of the studies support an association between hip adduction and iliotibial band syndrome (Gau et al., 2011).

Male runners with iliotibial band syndrome as opposed to the matched controls experienced a significantly greater degree of internal rotation of the hip and knee adduction during running (Noehren et al., 2014). A greater peak internal rotation of the hip angle ($p=0.01$) in female runners was reported in the study of Noehren et al. (2007). Greater internal rotation of the hip angle may be associated with the risk of iliotibial band syndrome in male and female runners (Noehren et al., 2007; Noehren et al 2014)

The symptom of pain in iliotibial band syndrome usually occurs in a runner after having suddenly begun running after a considerable period of rest (Brukner & Khan, 2012). The association between the onset of pain in iliotibial band syndrome and muscle fatigue was investigated in a study where runners ran on a treadmill at an average pace of 3.2 m/s (SD 0.29) until they were fatigued at approximately 25.6 minutes (SD 8.3). They exhibited less peak adduction of the hip angles when they were fatigued as opposed to the healthy runners. This was postulated to have been due to their implementation of a mechanism of reducing the intensity of the pain that they felt as their running pace increased (Brown, 2016).

2.7.3.6 Conclusion on iliotibial band syndrome

Training factors such as excessive downhill running and a fast increase in running intensity are associated with the risk of iliotibial band syndrome (Saika & Tepe, 2013). Female runners with a history of iliotibial band syndrome present with less hip adduction in running compared to matched controls (Foch et al 2013; Grau et al., 2011; Noehren et al., 2007). Male runners with iliotibial band syndrome present with a greater hip internal rotation angle than matched controls (Noehren et al., 2014; Noehren et al., 2007).

2.7.4 Achilles tendinopathy

2.7.4.1 Introduction

Achilles tendinopathy is a common injury arising from the overuse of the Achilles tendon. Tendinopathy occurs either in the midportion or at the insertion of the tendon on the calcaneus (Brukner & Khan, 2012). The global incidence of Achilles tendinopathy is 9.1% to 10.9% and the prevalence is 6.2% to 9.5% (Lopes et al., 2012). Achilles tendinopathy is globally one of the main running related injuries in ultra-marathon runners (Lopes et al., 2012). The incidence of midportion Achilles tendinopathy in the general Dutch population is 1.85 per 1000 registered patients. No correlation could be found between sports activity and the diagnosis in 35% of the cases reported (de Jonge et al., 2011).

2.7.4.2 Symptoms and clinical presentation

The patient with Achilles tendinopathy will complain of pain that increases after an activity. The pain subsides with either warming up or beginning an activity, and when the activity ceases, usually after cool down, the pain resumes again. Athletes tend to continue physical exercise despite this pain, thereby altering the healing process and causing increased damage to the tendon. A clinical examination of palpation may reveal local tenderness of the tendon and thickening when compared with a normal tendon (Brukner & Khan, 2012).

2.7.4.3 Pathophysiology and mechanism of injury

Tendinopathy occurs due to strain in tendons during vigorous exercises such as high-intensity running and a high load of upslope running. This results in a change in the tendon structure. Owing to the stress, the bundles of collagen disarray and separate (Brukner & Khan, 2012). The Type III collagen increases and the once abundant Type I collagen decreases. This increase in the presence of Type III collagen causes the tendon structure to weaken (Cook et al., 2014).

In the event of chronic Achilles tendinopathy, there are changes in the peritendinous tissue which contribute to the worsening of the condition. Fibroblast and myofibroblasts have been identified in the peritendinous tissue of a pathological Achilles tendon. This causes scarring and a degeneration of the tissue surrounding the tendon and, therefore, a diminished surface area for the vessels and nerves to pass through to the tendon. At the same time, the pathological tissue surrounding the Achilles tendon undergoes proliferation, which causes increased tension in the tendon itself. The result of this is an increase in friction between the peritendinous tissue and the tendon, the crural facia and the skin. This further increases the tension generally (Jarvinen et al., 1997).

Zanetti et al. (2003) also noted a reduction in the lumen space between the tendon and the paratenon in pathological tendons, which also leads to increased tension. The tendons also exhibited an increased nerve and arterial supply in comparison to healthy tendons (Ackerman et al., 2016; van Sterkenburg et al., 2011). The main cause of pain in Achilles tendinopathy was from the surrounding tissues and not from the tendon itself (Magnan et al., 2014; van Sterkenberg et al., 2011).

2.7.4.5 Risk factors associated with Achilles tendinopathy

Risk factors associated with Achilles tendinopathy are multifactorial (Lorimer et al., 2014). On account of the lack of prospective studies to determine the causes of Achilles tendinopathy, a Delphi study was conducted. In the Delphi study involving 16 leading tendon experts, the risk factors for Achilles tendinopathy were explored and deliberated upon. The Delphi study consisted of three rounds of deliberation. The intrinsic and extrinsic risk factors were categorized separately into an active/athletic group and an inactive/sedentary group respectively. Ten intrinsic and ten extrinsic risk factors were reported respectively in order of importance. In the intrinsic risk factors associated with the development of Achilles tendinopathy in the active/athletic category, the following were acknowledged: previous lower limb tendinopathy, recent injury, an increase in age, gender, muscle power/strength, exposure to steroids, reduced ankle dorsiflexion, weight, antibiotic treatment, and lastly, foot pronation (Pingel et al., 2012). The extrinsic risk factors in the active/athletic category were reported as changes in loading, training errors, activity levels, footwear, and lastly, training surface.

In the inactive/sedentary category, the intrinsic risk factors associated with the development of Achilles tendinopathy in order of priority were found to be : advancing age, obesity (Kozlovskaia et al., 2017), gender, recent injuries, and previous lower limb tendinopathy, weight, diabetes mellitus, exposure to steroids, high cholesterol levels, and lastly, rheumatologic disease. Generally, the intrinsic risk factors in this group of individuals were noted to be associated with systemic changes. The extrinsic factors in this category included: changes in loading, activity levels, and footwear (O'Neill et al., 2016).

Lower limb biomechanics in those with Achilles tendinopathy differs from that of healthy individuals (Munteanu et al., 2011). A high braking force was found to be a risk factor for Achilles tendinopathy and individuals with high arches and high levels of vertical force were found to be at less risk in terms of Achilles tendinopathy (Kozlovskaia et al., 2017; Lorimer et al., 2014).

2.7.4.6 Hip dysfunction in Achilles tendinopathy

Neuromotor control of the gluteus medius and maximus muscles were investigated in runners with Achilles tendinopathy and in their matched controls. Runners with Achilles tendinopathy experienced a delay ($p<0.001$) and a shorter duration ($p<0.001$) in the activity of the gluteus medius muscle at the heel strike phase as opposed to these same aspects in healthy runners. They also demonstrated a delay ($p=0.008$) and a shorter ($p=0.002$) duration and an earlier offset time ($p<0.001$) compared to these aspects in healthy runners. It was concluded that a delay and a shorter duration in the activity of the gluteus medius muscles are associated with Achilles tendinopathy in runners (Franettovich et al., 2014).

2.7.4.7 Conclusion on Achilles tendinopathy

Risk factors that may be associated with Achilles tendinopathy are multifactorial and warrant further prospective research (Lorimer et al., 2014). Pain in Achilles tendinopathy is primarily from the surrounding tissues and less from the tendon itself (Magnan et al., 2014; Sterkenberg et al., 2011). Runners with Achilles tendinopathy presented with neuromotor control of the gluteus medius and maximus muscles specifically a delay and shorter duration in activity (Franettovich et al., 2014).

2.7.5 Plantar fasciitis

2.7.5.1 Introduction

Plantar Fasciitis is one of the most common overuse running-related injuries resulting in pain felt on the plantar surface of the foot (Brukner & Khan, 2012). The global incidence of plantar fasciitis ranges from 4.5% to 10.0%, and the prevalence from 5.2% to 17% in runners (Lopes et al. 2012).

2.7.5.2 Symptoms and clinical presentation

One of the main symptoms of plantar fascia is pain felt under the foot first thing in the morning (Brukner & Khan, 2012). The pain is usually located on the medial side of the calcaneal tuberosity under the foot and tenderness felt in the same area on palpation. The pain usually increase with walking and running (Tae Im Yi et al., 2011).

2.7.5.3 Pathophysiology and mechanism of injury

Plantar fasciitis occurs due to overuse of the plantar fascia predominantly at the attachment to the calcaneus. The condition causes the collagen of the plantar fascia to disarray and degenerate. It is important to note there is no inflammation and thus the condition is similar to that of a tendinosis (Brukner & Khan, 2012). Activities that need repetitive simultaneous movement of maximal ankle plantarflexion and dorsiflexion of the metatarsophalangeal joints e.g. running are the culprits to onset the condition (Brukner & Khan, 2012)

The plantar aponeurosis is a thick facia made of fibrous tissue that originates proximally from the calcaneal tubercle and attaches distally on the forefoot. The thick aponeurosis is divided into three parts, the central part which is the thickest and the medial and lateral parts. The medial part attaches to the abductor hallucis muscle and the lateral part attaches to the abductor digiti minimus muscle. The central part further divides into five bundles which attach to the proximal phalanges via the plantar plates (Chen et al., 2013). The plantar fascia in patients

diagnosed with plantar fasciitis was examined using ultrasound imaging for fascia thickness and vascularity. Vascularity was assessed using the vascular index (VI), pain was assessed with the visual analogue scale and foot function was assessed using the foot function index (FFI). The fascia in plantar fasciitis has a significantly higher vascularity (mean±SD, 2.4±1.4%) and is thickened (5.0±1.3mm) when compared to normal fascia on the unaffected limb of a patient. The vascularity of the unaffected limb was (1.4%±0.5%) and the fascia thickness (2.9±0.6 mm). Pain perceived by the patients was associated with the fascia vascularity. Fascia vascularity and thickness were both associated with foot function index which demonstrated a 42% difference to the unaffected foot (Chen et al., 2013).

The Windlass mechanism is described by Hicks, (1954) as a mechanism that occurs when the toes are pulled into extension and thereby causing the plantar aponeurosis to tighten. At the same time the aponeurosis is also pulled distally and causes the longitudinal arch to rise due to the shortened distance between the calcaneal tubercle and the metatarsophalangeal heads (Hicks, 1954; Kappel-Bargas, 1998). The windlass mechanism occurs when the first metatarsophalangeal joint is extended which occurs during the push off phase of normal walking and running (Kappel-Bargas, 1998; Wager et al., 2016).

2.7.5.4 Risk factors associated with plantar fasciitis

Tightness of the gluteus, hamstrings or the calf may increase ones risk of plantar fasciitis (Brukner & Khan, 2012). Labovitz et al. (2011) found supporting results in a prospective study which revealed that tightness of hamstring muscles and the gastrocnemius-soleus complex were statistically associated with plantar fasciitis ($p<.0001$). Different types of runners are more susceptible to plantar fasciitis (Di Caprio et al., 2010). Competitive runners were found to be at a higher risk of plantar fasciitis (70.9% of cases) than middle distance runners (51.7%) (Di Caprio et al., 2010). A high arched foot is associated with decreased mobility of the foot in patients with plantar fasciitis. The plantar fascia length was also found to be reduced when assessed in a weight bearing state (Sahin et al., 2010).

It is recommended that clinicians assess all risk factors of plantar fasciitis in order to effectively manage the condition (Martin et al., 2014). According to the clinical practical guidelines of 2014; limited dorsiflexion of the ankle joint (van Leeuwen et al., 2016; Waclawski et al., 2015) , weight bearing conditions (Waclawski et al., 2015) and a high body mass index in non-athletes (van Leeuwen et al., 2016; Labovitz et al., 2011) should be assessed (Martin et al., 2014).

2.7.5.5 Hip dysfunction and plantar fasciitis

To date there is no significant evidence that proves the association of hip dysfunction and plantar fasciitis. In a case report of a 44 year old woman, a treatment program that consisted of strengthening hip ex flexors, extensors, abductors and adductors and passive ankle joint manipulation yielded positive results. Pain intensity decreased from a baseline of six to a final score of one (Dos Santos et al., 2016). This was contrary to the results of Kamonseki et al. (2016) where a strengthening programme of the hip abductors and lateral rotators yielded no significant results compared to a foot exercise or stretching programme.

2.7.5.6 Conclusion on plantar fasciitis

Plantar fasciitis is a common overuse injury in runners (Lopes et al., 2012). Runners with high arches are at a higher risk of plantar fasciitis (Ribeiro et al., 2011). To our knowledge, there is no evidence supporting the association of hip dysfunction with plantar fasciitis.

2.8 The role of the hip in running-related injuries

2.8.1 Anatomy of the hip

The hip joint is the largest ball-and-socket joint in the body. It consists of the articulation between the femoral head and the acetabulum. The acetabulum consists of three innominate bones, namely the ilium, the ischium and the pubis (Byrne et al., 2010). The femoral head is joined to the femoral long bone by the neck, which is approximately five centimetres long in an adult (Byrne et al., 2010; Hughes et al., 2002). The angle at which the neck of the femur is connected to the femur bone is called the

angle of inclination. This angle is formed by the intersection of an imaginary line drawn down the long bone of the femur and a line drawn through the longest part of the femoral neck. This angle varies in people, but a normal angle generally varies between 120 and 125 degrees (Byrne et al., 2010; Hughes et al., 2002).

An angle smaller than this results in a deformity of the hip called a *coxa vara* (see Figure 1), which predominantly influences the anatomy and biomechanics of the hip and other areas of the kinetic chain. The *coxa vara* deformity predisposes one to develop knee valgus owing to the fact that the knee compensates for the reduced angle of inclination (Magee as cited in Daneshmandi et al., 2011). A reduction in the angle of inclination results in an increase in the adductor moment during the stance phase. This adductor moment may further increase in the absence of adequate abduction strength in the hip (Daneshmandi et al., 2011). An increased angle of inclination results in a deformity of the hip called a *coxa valgum*. The resultant change in anatomy and biomechanics at the hip joint influences the lower back, the knee and the ankle joints (Hughes et al., 2002). Hip *coxa valga* has been linked to *genu varum*, which is a mal-alignment of the knee joint in a varus position (Powers, 2010).

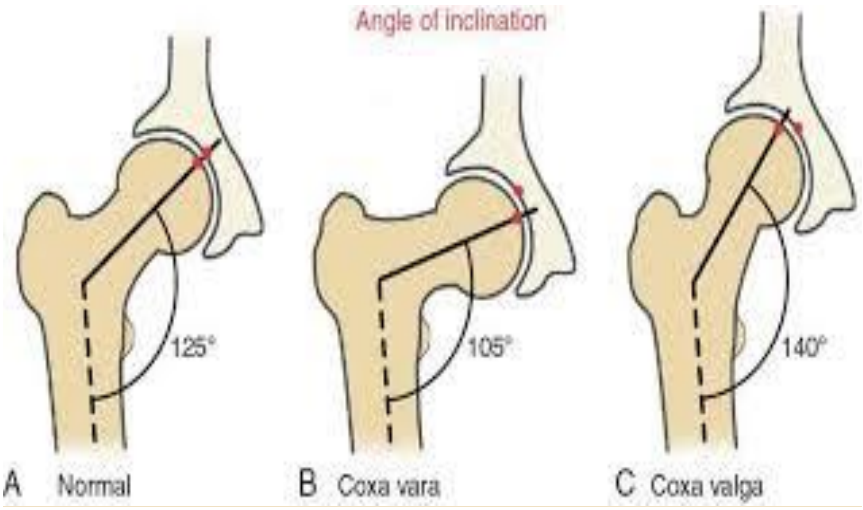


Figure 2. Angle of inclination (Somerset 2014)

Souza and Powers, (2009) investigated anatomical and biomechanical femoral differences in women suffering from patellofemoral pain syndrome and their matched pain-free and healthy controls. It was found that women with patellofemoral pain syndrome had an increased femoral angle of inclination

(132 degrees ±5.2 degrees vs. 128 degrees ± 5.0 degrees; p=.011) compared to their controls. The results suggest that an increased angle of inclination could possibly predispose women to patellofemoral pain (Souza & Powers, 2010).

The medial and lateral femoral condyles articulate distally with the medial and lateral tibial condyles and the patella, thus forming the knee joint. The angle formed by the axis of the femoral head and the neck and the femoral condyles is known as the angle of torsion. A normal angle varies between 12 and 15 degrees. A larger angle of torsion is described as anteversion and a smaller angle as retroversion (Byrne et al., 2010; Wheeles, 2012). The normal angle of torsion results in the femur being functionally positioned for slight internal rotation (Wheeles, 2012).

Anteversion of the hip thus results in greater internal rotation, which predisposes one to walk with an in-toeing gait and may result in the patella being displaced medially (Wheeles, 2012; Daneshmandi et al., 2011). An increased internal rotation of the knee causes the axis of the femur to be in a greater adduction position resulting in the tibia being in a more abduction position (Magee as cited in Daneshmandi et al., 2011).

Anteversion of the hip is associated with a larger Q angle (Daneshmandi et al., 2011). Anteversion of the hip has been linked to the possible development of an anterior cruciate ligament injury (Kaneko & Sajyraba, 2013). On the other hand, retroversion of the hip results in less internal rotation than what is deemed normal and results in an out-toeing gait, resulting in the tibia being in a more adduction position (Wheeles, 2012).

Satpathy et al. (2015) completed a study on the association between femoral neck retroversion and femoroacetabular impingement in a cadaveric study. It was concluded that a hip with proximal retroversion of the femur would result in high mean peak joint pressure. Peak joint pressure occurs in flexion of the hip and should be deemed as a possible risk factor in femoroacetabular impingement. Furthermore, the presence of femoroacetabular impingement was found to be a factor contributing to the development of osteoarthritis of the hip (Moya et al., 2010).

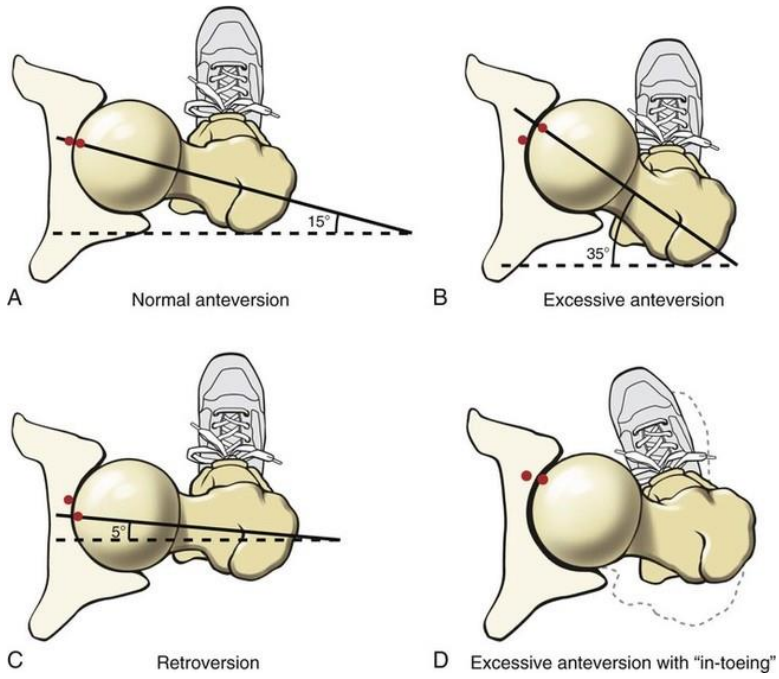


Figure 3. Superior view of the right hip, indicating the angle of torsion

(Neumann DA: Kinesiology of the musculoskeletal system: foundations for physical rehabilitation, ed 2, St Louis, 2010, Mosby, Figures 12-8 and 12-9, B.)

The osteokinematic movements that are possible in the hip joint occur across three different planes. Flexion and extension occur across the saggital plane, abduction and adduction across the frontal plane, and external and internal rotation across the transverse plane. Circumduction of the hip is a circular movement that occurs in all planes of the hip joint (Byrne et al., 2010; Hughes et al., 2002).

The muscles around the hip joint are responsible for osteokinematic movements. The range of movement in the hip joint depends on the arthrokinematic movements, which are the movements between the two articulating surfaces and the ligaments, as well as on the strength and flexibility of the muscles (Byrne et al., 2010; Hughes et al., 2002).

The main muscle responsible for a movement is called the prime mover and the muscles helping the prime mover in its action are called the secondary movers. The muscles that help the prime mover are called the synergists; these are the neutralizers, the stabilisers and the fixators. The neutralisers cancel the unwanted movement of other muscles, the stabilisers surround the hip joint and increase stability, and lastly, the fixators are the muscles that contract in their agonist and antagonist groups in order to fixate the joint (Janda, 2013).

The main difference between the stabilisers and fixators is that the fixator is a type of stabiliser that prevents movement that occurs at the origin of the primary mover (Troy, 2011). The stabiliser has been further defined by Sangwan et al. (2014) in a systematic review that aimed to formulate a definition for muscle stabilisers "as muscles that contribute to joint stiffness by co-contraction and show an early onset of activation in response to perturbation via either a feed-forward or a feedback control mechanism" (Sangwan et al., 2014 pp 355).

The muscular system (muscles, tendons, ligaments, and fascia), the nervous system, and the joints, all form a movement system called the kinetic chain (Karandikar & Vargas, 2011). This movement system is what physically makes it possible for us to run, walk, kick, throw, swim, squat and perform other coordinated functional movements. The kinetic chain is made up of links, which are individual segments of the body that influence other links and must be moved in a particular sequence to achieve a specific movement. The sequencing of movement starts proximally to distally on account of the stability one needs proximally for peripheral movements. A disturbance in the lower limb kinetic chain increases susceptibility to injuries (Brukner & Khan, 2012; Karandikar & Vargas, 2011).

2.8.2 The Biomechanical link between the hip and the lower limb

The biomechanical link between the hip and the lower limb has been investigated by several researchers in their exploration of a possible causal association that could help in developing appropriate injury-prevention strategies. Studies that are prospective in nature have the advantage of being able to find this kind of association (Moola et al., 2015)

Hip dysfunction is the impairment of the structures or movements of the hip. Hip dysfunction may include but is not limited to poor muscle strength, poor hip control, an excessive or a limited range of motion of the hip, mal-alignment of the hip and faulty hip-running biomechanics. The skeletal structure of the body is linked together by ligaments, tendons, muscles and fascias (Brukner & Khan, 2012). A proximal movement in the link may cause a distal movement. The proximal movement in this case is presumed to be in the hip joint and the distal movement in the lower limb. The type of distal movement depends on whether the proximal movement occurs in a closed or open kinetic chain, and on the magnitude of the movement. A closed kinetic chain movement is a movement that occurs

when the distal part of the body remains in contact with a surface, while an open kinetic movement occurs when the distal part of the body is free (Brukner & Khan, 2012).

During running, the initial contact and midstance phases occur in a closed kinetic chain. Throughout the running cycle, the athlete's pronated or supinated feet affect the proximal movements of the joints in a distinctive way. Pronation of the foot causes eversion at the subtalar joint, which causes the abduction of the forefoot, dorsiflexion at the talocrural joint, and the internal rotation of the tibia. These distal movements cause a flexion-valgus position to occur at the knee. This knee position causes an anterior and forward pelvic rotation and pelvic elevation ipsilateral to the pronated foot. This results in the lumbosacral spine assuming an extension and a lateral flexion pattern ipsilaterally (Nicola & Jewison, 2012; Dicharry, 2014).

The start of the swing phase of running marks the beginning of supination, which occurs, in the open kinetic chain. This causes inversion, which occurs at the subtalar joint, and then forefoot adduction. Plantarflexion then occurs at the talocrural joint which causes the external rotation of the tibia. These distal movements cause a varus position to occur at the knee, which causes external rotation of the hip, abduction and extension. This results in the lumbosacral spine assuming an extension and a lateral flexion pattern on the side opposite to that experiencing supination (Nicola & Jewison, 2012; Dicharry, 2014).

The hip and the lower limb are certainly linked in a normal running gait cycle (Nicola & Jewison, 2012; Dicharry, 2014). The link is not only distal to proximal but also proximal to distal (Reiman et al., 2009). As opposed to men, healthy women display greater femoral adduction and knee abduction (Baldon et al., 2011). Heinert et al. (2008) investigated the effect of hip abductor strength on lower limb kinematics during running in a prospective observational study. The participants consisted of female recreational runners who had their hip abductors tested with a handheld dynamometer. Using an instrumented running analysis test to obtain kinematic data, an assessment was made of those female runners who had the greatest strength in their hip abductors and of those who had the least strength in their hip abductors. The results revealed that female recreational runners with relative weaknesses in their hip abductors exhibit a larger angle of knee abduction in the stance phase of running ($p<0.05$) (Heinert et al., 2008). A larger knee abduction angle has been associated with the

increased risk of patellofemoral pain syndrome (Brukner & Khan, 2012) and anterior cruciate ligament injury (Sigward et al., 2015; Hewett et al., 2005). Furthermore, a larger knee valgus and an internal rotation angle of the hip were found to be associated with greater knee valgus moments during a side-step movement of 110 degrees. This is the motion in which anterior cruciate ligament injuries typically occur (Sigward et al., 2015). Eccentric strength of the hip abductors may be associated with the abduction angle of the knee in male recreational runners with no history of running-related injuries (Korsgaard et al., 2015).

An increase in the internal rotation of the hip and hip adduction in standing causes an increase in medial joint stress on account of a medial shift in the knee joint line. This causes the abduction of the knee joint in order to compensate for the medial shift and thus results in pronation of the foot (Powers, 2010; Baldon et al., 2011; Brukner & Khan, 2012). Owing to these changes, the centre of gravity during walking then shifts medially to the subtalar joint instead of centrally (Brukner & Khan, 2012). This is the typical pattern of a functional knee valgus picture (Powers, 2010).

Similarly, an increased internal rotation angle of the hip during a jumping-landing functional exercise was found to be predictive of patellofemoral pain syndrome in a prospective cohort study of 1 597 midshipmen (Boling et al., 2009). Cashman, (2012) confirmed this finding in a systematic review on the kinematics of the knee valgus. Cashman (2012) found that participants with increased knee valgus presented with weak hip abductors. Abnormal hip biomechanics affects the kinematics and kinetics of the lower limb (Powers, 2010; Cashman, 2012). What is questioned is the nature of the association between hip dysfunction and running-related injuries in long-distance runners.

Evidently the movement of proximal structures such at the hip joint is able to influence more distal structures such as the ankle joint or the knee. The kinetic chain link assists us in understanding musculoskeletal movements on a deeper level.

2.9 Running biomechanics

Running biomechanics is the manner in which the body moves in running, more specifically the effect that the musculoskeletal system and gravity have on the movement of the body. This also entails the forces acting on the body during running. (Novacheck, 1998). The running biomechanics of an athlete

can put them either at an advantage or at a disadvantage of placing in a race (Moore, 2016). An athlete with poor running biomechanics not only consumes more energy but is also more susceptible to sustain running-related injuries (Nicola & Jewison, 2012). The normal running biomechanics will be explained to indicate how running-related injuries can develop in the presence of abnormality.

Running occurs at a faster pace than walking with the main difference being the absence of the double-support period in running, as opposed to walking, when both feet are on the ground at the same time (Brukner & Khan, 2012). In addition, there is a flight phase, known also as the double-float period in running. It is characterised by both feet being off the ground at the same time between the stance phases (Brukner & Khan, 2012). The double-float period occurs between the toe-off phase and the beginning of the initial swing phase, and again at the end of the terminal swing phase and just before the initial contact phase (Greenberg et al., 2014). As the running speed increases, so does the double-float period; the two are directly proportional to each other (Souza et al., 2016; Brukner & Khan, 2012).

The running stride is made up of two phases, namely the stance phase, which accounts for 40% of the stride cycle, and the swing phase, accounting for the remaining 60%. The stance phase consists of the initial foot contact, the mid-stance phase and the toe-off phase (Stoggl & Wunsch, 2016). The period from the initial foot contact to the beginning of the mid-stance phase is characterised by hip (50 degrees), knee (40 degrees) and ankle (10 degrees) flexion (Stoggl & Wunsch, 2016).

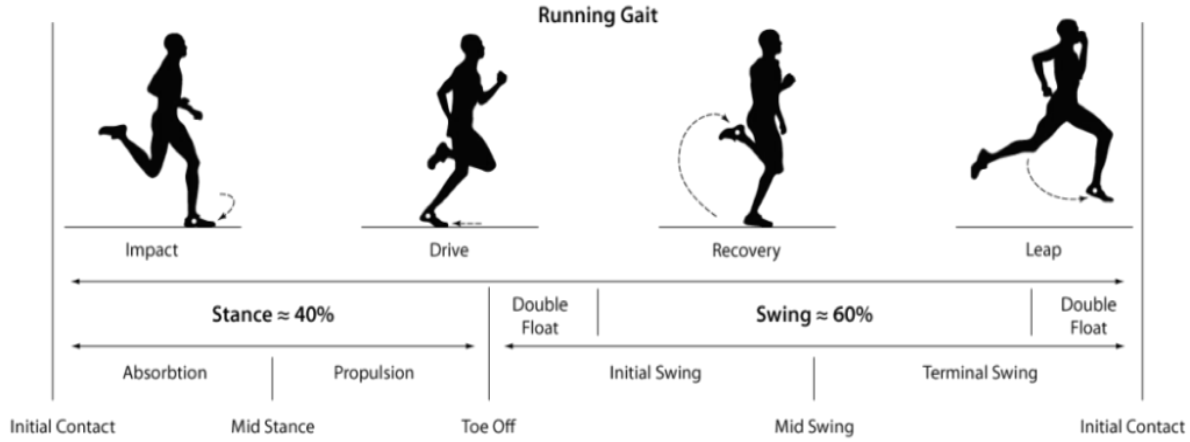


Figure 4 The running gait cycle (4- point run analysis) (www.kintec.net/blog/the-run-centre-4-point-run-analysis/)

At the mid-stance phase, which is the position when the foot is on the ground, the stance limb holds the entire weight of the runner, whilst the opposite limb is flexed at the knee (Stoggl & Wunsch, 2016). This is supported by evidence that at the beginning of the mid-stance phase, the quadriceps and hamstrings contract strongly (Hammer et al., 2010). The co-contraction of the quadriceps and hamstrings causes the hip to extend, and the knee and ankle to further flex to 60 and 25 degrees respectively (Novacheck, 1998; Mann cited in Loudon et al., 2013).

Between the mid-stance and the toe-off phase, the hip extends further to ten degrees but the knee starts to extend until it reaches about 40 degrees just before the toe-off phase. As the ankle joint plantar flexes and, as a result, pushes the foot off the ground, in so doing, it assists with propelling the body forward. (Novacheck, 1998; Mann cited in Loudon et al., 2013). The soleus and gastrocnemius muscles are responsible for the pushing- off action, which marks the end of the stance phase and the beginning of the swing and flight phases (Hammer et al., 2010).

The swing phase is the phase when the foot is off the ground. It comprises of three phases, firstly, the early swing phase, followed by the mid-swing phase, and lastly, by the terminal swing phase (Greenberg et al., 2014; Brukner & Khan, 2012). The early swing phase starts as soon as the foot is off the ground. At the start of the swing phase, the hip is still in extension, the knee is flexed and the ankle is at approximately 25 degrees of plantar flexion. As the early swing phase transitions into the mid-swing phase, the hip starts to flex and can reach the full range of motion depending on the running speed. The knee extends to 40 degrees and prepares for heel strike, which marks the beginning of the stance phase. Lateral rotation of the lower limb occurs in the mid-stance phase as the opposite leg swings past the stance leg. During the swing phase, the lower limb rotates medially and as the heel strike phase starts, the foot is pronated (Souza et al., 2016; Brukner & Khan, 2012).

A strike pattern is the way in which the foot of a runner touches the ground in the initial foot contact phase. There are three types of strike patterns, namely, the rear-foot, mid-foot and the forefoot strike pattern (Rogers et al., 2017). When the foot strikes the ground first - with the heel or the posterior one third of the foot -, the runner is said to have a rear-foot strike pattern. The mid-foot strike pattern is characterised by the foot contacting the ground with the heel and the area below the fifth metatarsal at

the same time. Lastly, a forefoot strike pattern is characterised by the foot contacting the ground first with the anterior third of the foot (Rogers et al., 2017).

The most common strike pattern in novice runners is the heel-strike pattern (Bertelsen et al., 2012). Strike patterns are influenced by intrinsic and extrinsic factors such as the running speed, the type of training of the athlete, fatigue, the wearing of shoes, the designs of the shoes, and the characteristics of the running surface (Lieberman et al., 2010; Breine et al., 2014). The optimal running gait that one should aim for is the normal gait, which ultimately conserves energy and minimises running injuries (Nicola & Jewison, 2012).

2.10 Deviations in running biomechanics

Running effectively requires optimal ranges of the joints (Brukner & Khan, 2012). An abnormal range of motion in the hip may result in the runner developing compensatory strategies, the most common being running with an abnormally larger lumbar extension, bounding and over striding (Nicola & Jewison, 2012).

Bounding is a compensatory strategy used when runners have a reduced extension in the range of motion of their hips. This pattern is characterised by increased hip flexion and a more powerful push off resulting in an increased float time and stride length (Souza et al., 2016). Running by bounding occurs at a higher intensity than running utilising the normal running gait and thus requires more energy (Souza et al 2016).

Over striding is a compensatory type of running pattern which is characterised by the runner's foot striking the ground anterior to the runner's centre of mass. This pattern results in an abnormally increased hip flexion and extension before the initial contact phase (Souza et al., 2016; Pipkin et al., 2016).

Abnormal running biomechanics can be detected by closely observing several factors, one of them being the cross-over sign, which is when the feet cross the midline of the body during running (Souza et al., 2016). Injuries such as tibial stress fractures and iliotibial band syndrome are associated with

over-pronation and excessive hip adduction (Neal et al., 2014; Newman et al., 2013; Noehren et al., 2012). Hip adduction is associated with a narrow base of support seen in runners with the cross-over sign. These runners would benefit from a gait re-training regime in order to correct their running style (Souza et al., 2016).[2]

2.11 Summary of literature review

A causal relationship between risk factors and the outcome of interest can only be concluded on the basis of high quality prospective studies and studies of association (Moola et al., 2015). Injury prevention should be at the forefront of the management of athletic injuries (Finch et al., 2011). The association between hip dysfunction and lower limb injuries has been studied thoroughly in well-researched and well-presented cross-sectional studies. Thus, the treatment of these conditions has a good foundation (Noehren et al., 2012).

Physiotherapists refrain from symptomatically treating conditions, but also look for the cause and contributing factors to the condition. It is, therefore, beneficial to know the aetiology and predisposing factors of running-related injuries. Running-related injuries are unique since they are largely not of a traumatic nature but rather as a result of overuse. This means that there are predisposing/causal factors that either can be adapted (extrinsic factors) or cannot (intrinsic factors). A knowledge of these factors will result in above-standard injury prevention mechanisms.

The most common running-related injuries are patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome, Achilles tendinopathy, and plantar fasciitis (Lopes et al., 2012). Hip dysfunction in running-related injuries has been investigated predominantly in cross-sectional studies with systematic reviews being dominated mainly by these studies. To date, what we have learnt from cross-sectional studies includes the following:

- Female runners with medial tibial stress syndrome have less muscle strength of the hip abductors as opposed to their matched healthy controls (Verrelst et al., 2014).

[2] Reference is made to the biomechanics of the hip in the section entitled ‘Hip dysfunction in runners’.

- Runners with medial shin pain have a larger lateral pelvic tilt, peak internal rotation of the hip, and less knee flexion, when compared to their matched controls (Loudon & Reiman, 2012).
- Runners with Achilles tendinopathy present with a delayed and shorter activation period of the gluteus medius muscles. They also present with an impaired offset time (Franettovich et al., 2014).
- Participants with patellofemoral pain present with a delayed and shorter activation period of the gluteus medius muscles during stair climbing (Rogers et al., 2017).
- Females with patellofemoral pain have greater hip abduction, an ipsilateral lean, a contra-lateral pelvic drop, knee adduction, internal rotation of the hip, less peak eccentric abduction of the hip, and less activation of the gluteus medius and greater gluteus maximus muscles when performing single leg squats. (Nakagawa et al., 2012; Willy et al., 2011).
- Female runners with iliotibial band syndrome present with lower velocities of the hip abductors (Foch et al., 2013) and less strength (Grau et al., 2011).
- Male runners with iliotibial band syndrome have greater degree of internal rotation in the hip and more knee adduction than their matched controls (Noehren et al., 2014).

According to this literature review, there is a link between the hip and lower quarter injuries. It is yet to be shown, whether the link in long-distance runners with running-related injuries is that of a proximal to distal in nature, with the proximal part being a hip dysfunction.

Chapter 3: Methodology

3.1 Introduction

This systematic review follows the approach of the Joanna Briggs Institute in respect of conducting systematic reviews of association as described by Moola et al. (2015). The methodology is described in the protocl published in the JBI Database of Systematic Reviews and Implementation Reports (protocol no : JBISRIR-2016-002961) (Olivier et al 2017) and PROSPERO (registration number CRD42017081376). Minor changes were made with respect to the outcome of interest of the systematic review as decribed in the protocol. The outcome of interest, namely "lower quarter injuries", was changed to " lower limb injuries". The reason for this change was due to a lack of literature on lower back injuries, which was initially included in the definition of "lower quarter injuries". Because the literature available reported on lower limb injuries, we saw it fit that the outcome of interest be adapted to a more specific and relevant outcome in long- distance runners.

3.2 Types of studies

Prospective and retrospective, observational and longitudinal cohort study designs were considered for inclusion. Experimental studies such as randomised control trials, quasi-experimental studies, or pre- and post-experimental studies were not included in the review. The reason for not including experimental studies in the systematic review was that the review aimed to establish hip- dysfunction-related associations or predictions of injury rather than modification strategies related to hip dysfunction that are commonly used in the rehabilitation of injury. Studies where the incidence of injuries was examined prospectively or retrospectively over a period of one month or longer were considered for inclusion in the study.

3.3 Inclusion criteria for studies

3.3.1 Population

This review considered studies that comprised of male and/or female long-distance runners who were 18 years and older, and long-distance runners who participated at all levels of performance. These studies included various populations of runners; novices, recreational, competitive, marathon and cross-country runners - all described by Kluitenberg et al. (2015). Long-distance runners were defined as runners who ran more than five kilometres at a time and had a total weekly mileage of at least 20 miles (32 km) (Macera, cited in Van Middelkoop, 2008). The participants were injury-free at the start of the studies and were followed up over a period of one month or more to monitor their incidence of injury.

3.3.2 Exposure of interest

Studies that investigated hip joint dysfunction as an independent variable were included in the review. Hip dysfunction included but was not limited to:

- poor hip muscle strength (e.g. based on dynamometer readings);
- poor hip control (e.g. the inability to perform a functional movement that requires good hip strength and control such as single leg bridging);
- excessive or limited hip range of motion (e.g. based on goniometer readings);
- hip mal-alignment (e.g. excessive femoral ante-version, based on x-ray); and
- poor hip-running biomechanics (e.g. excessive hip adduction when running, based on a biomechanical assessment).

3.3.3 Outcomes

The dependent variable in the review was lower limb injuries. The injuries were measured through either a clinical assessment by a health-care practitioner or a participant's self-report.

3.4 Search strategy

A search strategy that set out to find both published and unpublished studies was conducted in three phases from inception to July 2017. Firstly, a restricted search on MEDLINE and CINAHL was completed by searching text words in the titles and abstracts of papers using the key words, namely "running", "hip" and "injury". Secondly, another search was conducted using all the recognised keywords, as well as the index terms of the papers recovered in the initial search. The keywords "running", "hip", "injury" and "pain" were entered into all databases and a search for more studies was undertaken. Thirdly, the reference lists of all recognised studies and reports were scrutinised for more studies.

The following databases were searched: MEDLINE via PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), ProQuest Health, EBSCO MasterFile Premier, Physiotherapy Evidence Database (PEDro), Science Direct, PROSPERO, SCOPUS and SPORTDiscus with full text. Unpublished studies were searched on EBSCO MasterFile Premier. The primary keywords used were: "running", "hip", "injury" and "pain". The filter "humans" was applied where necessary.

3.5 Assessment of methodological quality

Articles retrieved were appraised on the basis of the Joanna Briggs Institute Meta-Analysis of Statistics Assessment and Review Instrument (JBI-MAStARI) for comparable cohort case control studies (Appendix I). The instrument is a standardised critical appraisal method for assessing studies and was developed by the JBI and collaborators. The instrument went through a peer review process and was approved by the JBI Scientific Committee (http: //www.joannabriggs.org/sumari. html) (Joanna Briggs Institute Reviewers Manual, 2015). Two independent reviewers critically appraised the studies for methodological quality and rated the studies on the basis of the tool (Table 2). All study results were analysed irrespective of the rating achieved. Disagreements were resolved through discussion (described in section 4.2). All studies that fitted the inclusion criteria, irrespective of methodological quality, were included in the review, although methodological quality was taken into consideration when assumptions from the results were drawn.

3.6 Data collection

The standardised data extraction tool from JBI-MAStARI (Appendix II) was used to extract data from the studies included in the review. Two reviewers independently extracted data and then compared the outcomes in order to minimise error. The following details were extracted: author(s), year of publication, short title, study setting and location, population, exposure of interest, outcome and results. The included studies were presented in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart (the Joanna Briggs Institute Reviewer's Manual, 2015) (Figure 5). All studies included in the systematic review are presented in Table 1. Full text studies that were retrieved but excluded are tabulated in Appendix III.

3.7 Data analysis and meta-analysis

Data analysis was completed by means of a narrative review. A meta-analysis could not be performed owing to the differences in the methodologies used in the included studies. Of the eight studies that were included in the systematic review, three studies measured hip dysfunction on the basis of more than one type of outcome measure (Dudley et al., 2017; Beard, 2015; Noehren et al., 2007). One study investigated hip dysfunction using a functional measurement tool called the Functional Movement screen tool (Hotta et al., 2015). Another study used measurements of muscle strength (Beard, 2015); six studies used kinematic measurements (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013 & 2007; Lun et al., 2004; Bennell & Crossley, 1996); and four studies used kinetic measurements (Dudely et al., 2017; Beard, 2015; Eskofier et al., 2012; Noehren et al., 2007).

The studies of Beard (2015), Eskofier et al. (2012) and Noehren et al. (2007) investigated hip abduction moment. In all three studies, participants underwent an instrumented biomechanical running analysis along a runway, hitting a force plate along the runway. It was not possible to pool results in a meta-analysis for the following reasons. The participants of Eskofier et al. (2012) ran at a speed of 4.0m/s, those of Noehren et al. (2007) at 3.7m/s and those of Beard, (2015) at a self-selected pace averaging 2.71±0.30m/s. Furthermore, the study of Eskofier et al. (2012) involved a small sample size owing to the high dropout rate and the lack of follow-up of participants in the study.

Also, no meta-analysis could be performed on any of the hip-related kinetic measurements. Hip

extension and flexion moments were investigated in only one study (Eskofier et al., 2012). Similar studies of firstly hip adduction moment (Dudley et al., 2017; Eskofier et al., 2012) and secondly, internal rotation moment, were undertaken (Eskofier et al., 2012). Hip adduction moment was investigated by means of an instrumented biomechanical running analysis, although the speed of running and the instance where measurements were taken differed.

Runners in the study of Eskofier et al. (2012) ran down a 30m runway at a controlled speed of 4.0 ±0.2m/s and hit a force plate in the centre of the runway, while those reported by Dudley et al. (2017) ran at a self-selected speed average of 3.84m/s along a 15m runway. Measurements in the study of Eskofier et al. (2012) were taken from contact phase to toe-off phase from the force plate in continuous time frames, while those in the study of Dudley et al. (2017) were taken in the stance phase of running when the force plate was struck.

The muscle strength of the hip abductors, extensors, flexors and external rotators was investigated in one study (Beard, 2015) with the aid of a handheld dynamometer. Although the position in which the measurements were taken differed, two studies investigated the internal and external passive range of motion of the hip using a goniometer (Lun et al., 2004; Bennell & Crossley, 1996). However, on account of the differences in the methods used to measure the internal and external rotation of the hip in the two studies, a meta-analysis of this factor could not be completed.

One study measured the active range of motion (Lun et al., 2004) and the other the passive range of motion of the hip (Bennell & Crossley, 1996). The study of Lun et al. (2004) measured active range of motion with the subjects sitting over the edge of a bed with their feet suspended. In contrast, the study of Bennell and Crossley, (1996) measured passive range of motion of the hip with the subjects in the prone position and the knee flexed to 90 degrees.

The hip adduction angle was investigated in four studies (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013; Noehren et al., 2007). The runners in the studies ran at different speeds, those in the study of Dudley et al. (2017) ran at 3.83m/s, those in the study of Beard, (2015) at 2.71-2.83m/s, and those in the study of Noehren et al. (2013 & 2007) at 3.7 m/s. In all the studies, data were collected when the runners struck the force plate in the stance phase. The data in the study of Noehren et al. (2013 &

2007) were collected when the runner struck the force plate in the centre of the runway at 120Hz.

Dudley et al. (2017), Beard, (2015) and Noehren et al. (2013) investigated the internal rotation of the hip during the stance phase. Hip abduction and external rotation angles were investigated in only one study (Beard, 2015). The above factors were taken into consideration and it was therefore decided that a meta-analysis of the results could not be done. As such, the results were presented in a more detailed narrative form.

3.8 Ethical considerations

No human participants were involved in this study; therefore, the researchers obtained an ethical clearance waiver through the University of the Witwatersrand's Human Research Ethics Committee (Ref: W-CJ-160420-2) (Appendix IV).

Chapter 4: Results

4.1 Study selection

A total of 3 016 study records were identified using the key words “hip”, “injury”, “pain” and ”running” as described in the methodology. (Refer to Figure 5, the PRISMA 2009 flow diagram, for a presentation of the search strategy). A total of 34 full text studies were scrutinised and excluded, the reasons being presented in Appendix III. Eight studies were finally selected to be included in the systematic review (Dudely et al., 2017; Beard, 2015; Hotta et al., 2015; Noehren et al., 2013 & 2007; Eskofier et al., 2012; Lun et al., 2004; Bennell & Crossley, 1996).

4.2 Methodological quality of the studies

One study was rated 11/11 (Dudley et al., 2017), two studies were rated 10/11 (Hotta et al., 2015; Eskofier et al., 2012), four studies were rated 9/11 (Beard, 2015; Noehren et al., 2013 & 2007; Lun et al., 2004) and one study was rated 8/11 (Bennell & Crossley, 1996). Overall, the methodological quality of the studies was high (Table 2). Most of the studies were unclear about the strategies to used to address the incomplete follow-up of participants (Table 2). In five of the studies, certified health-care professionals evaluated the outcome variable, which was “a running-related injury” (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013 & 2007; Eskofier et al., 2012). The health-care professionals consisted of sports medicine doctors, physicians, certified athletic trainers and physiotherapists. The remaining two studies used a self-reporting method (Hotta et al., 2015; Bennell & Crossley, 1996).

For this study, two reviewers appraised the full texts. Disagreement on the scoring of the studies was deliberated upon and solved by the two reviewers. One of the disagreements was about the validity and reliability of self-reporting of running-related injuries as an effective method of evaluation. It was decided that it would be considered reliable and valid if injuries were reported according to the area of the body affected and not as a diagnosis, although in the study of Bennell & Crossley, (1996), the former was concluded to be unreliable.

The participants in the study of Bennell & Crossley, (1996) were required to recall information pertaining to their injuries 12 months prior to the study. This posed a high risk in terms of the reliability of the information in that the information passed on stood a strong chance of being inaccurate.

The studies of Eskofier et al. (2012) and Lun et al. (2004) showed high dropout rates and a poor follow-up of participants. As such, the study of Eskofier et al. (2012) incorporated only a small sample size. The eight studies together obtained a mean score of 9/11.

Figure 5: PRISMA 2009 Flow Diagram

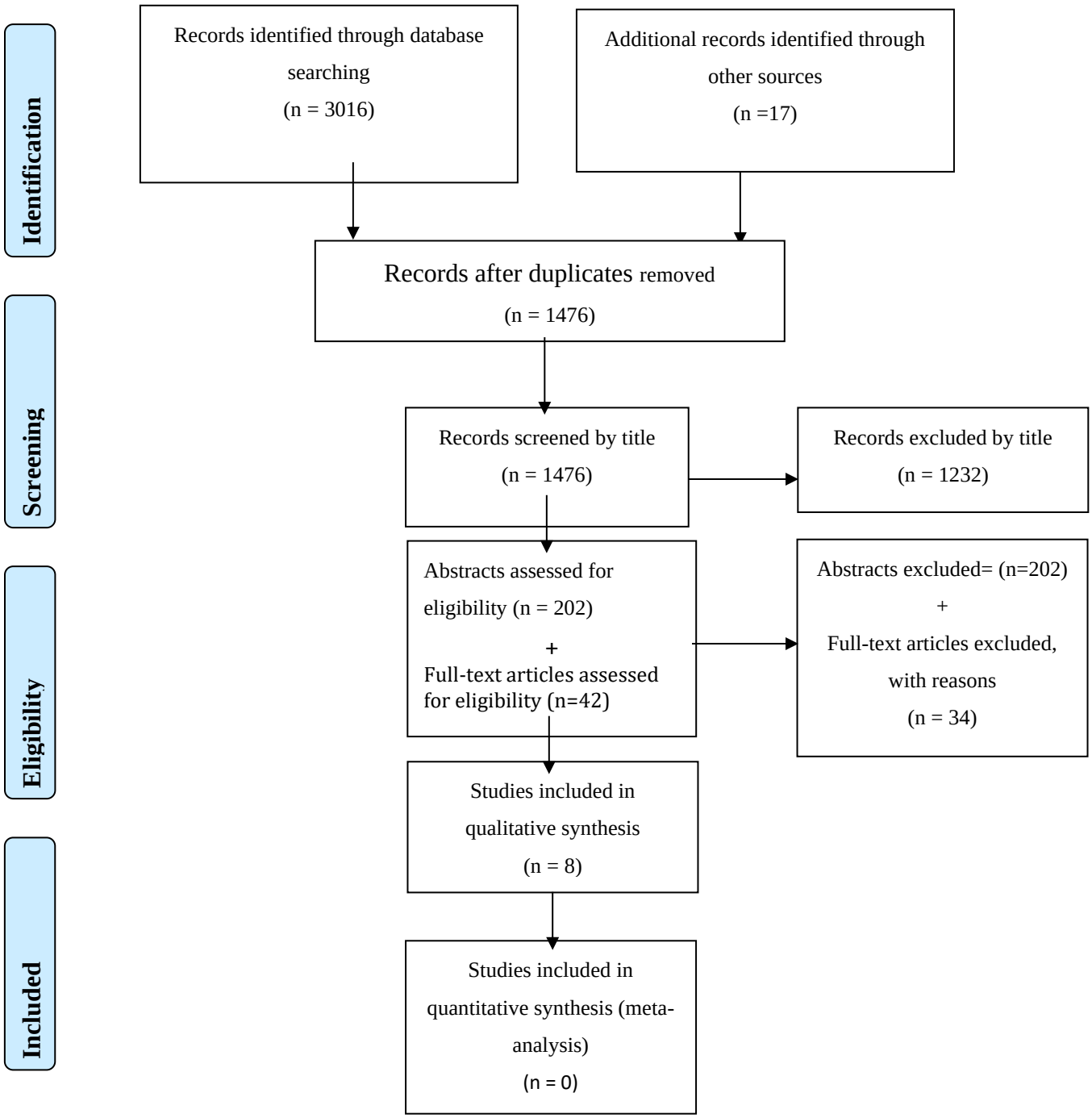


Figure 5: From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org

Table 1: JBI Checklist for Cohort Studies

Study	Dudley et al. 2017	Noehren et al. 2013	Noehren et al. 2007	Eskofier et al. 2012	Lun et. al 2004	Hotta et al 2015	Bennell & Crossley, 1996	Beard 2015
1. Were the groups similar and recruited from the same population?	Y	Y	Y	Y	Y	Y	Y	Y
2. Were the exposures measured in a similar way to assign people to both exposed and unexposed groups?	Y	Y	Y	Y	Y	Y	Y	Y
3. Was the exposure measured in a valid and reliable way?	Y	Y	Y	Y	Y	Y	Y	Y
4. Were confounding factors identified?	Y	Y	Y	Y	Y	Y	Y	N
5. Were the strategies to deal with confounding factors stated?	Y	Y	Y	Y	Y	Y	N	N
6. Were the groups /participants free of the injury at the start of the study (or at the moment of exposure)?	Y	Y	Y	Y	Y	Y	Y	Y
7. Were the outcomes measured in a valid and reliable way?	Y	Y	Y	Y	Y	Y	N	Y
8. Was the follow-up time reported and was it sufficient for outcomes to occur?	Y	Y	Y	Y	Y	Y	Y	Y
9. Was follow-up complete, and if not, were the reasons for loss of follow-up described and explored?	Y	NC	NC	Y	Y	Y	Y	Y
10. Were there strategies in place to address incomplete follow-up used	Y	NC	NC	NC	N	NC	N	Y
11. Were appropriate statistical analyses used?	Y	Y	Y	Y	Y	Y	Y	Y
Total 11	11	9	9	10	9	10	8	9
KEY –TOTAL								
not applicable NA								
yes Y								
no N								
unclear NC								

4.3 Study characteristics

Of the eight studies included in the systematic review, seven were prospective cohort studies (Dudely et al., 2017; Hotta et al., 2015; Beard, 2015; Noehren et al., 2013; Eskofier et al., 2012; Noehren et al., 2007; Lun et al., 2004); and one study was a retrospective cohort study (Bennell & Crossley, 1996. The study of Beard, (2015) was a dissertation for a Doctor of Philosophy Degree in Exercise Science. The number of participants in the eight studies collectively amounted to 1 151. They were included in the narrative analysis of the data.

The participants included in the studies had a mean age of 28.6 years. The study of Dudley et al. (2017) included the youngest participants with a mean age of 19.8 years, while Beard's study, (2015) included the oldest participants with a mean age of 39 years. Four studies included both male and female participants (Dudley et al., 2017; Eskofier et al., 2012; Lun et al., 2004; Bennell & Crossley, 1996); three studies included only female participants (Noehren et al., 2013 & 2007; Beard, 2015); and one study included only male participants (Hotta et al., 2015).

The studies included in this systematic review had an adequate follow-up time of more than one month. The study with the least time to follow-up on was that of Dudley et al. (2017) with a follow-up period of 14 weeks. Beard (2015) was the next in line with a follow-up period of four months; then three studies followed with a follow-up period of six months (Hotta et al.,2015; Eskofier et al., 2012; Lun et al., 2004); Bennell and Crossley (1996) had a follow-up period of 12 months; and lastly, two studies had the longest follow-up period of 24 months each (Noehren et al., 2013 & 2007).

4.4 Definition of types of runners

The types of runners included in the studies varied. Beard (2015) did not classify the type of runners included in his study. The majority of the studies included recreational runners (Eskofier et al., 2012; Noehren et al., 2013 & 2007; Lun et al., 2004). The study of Dudley et al. (2017) included collegiate cross-country runners, and only one study included competitive runners (Hotta et al., 2015).

Competitive runners were described as middle- or long-distance runners competing in running competitions (Hot et al., 2014). The study of Bennell and Crossley (1996) included distance runners, classified as runners who had run in three-, five- and ten-kilometre races, as well as in marathon races.

Of the four studies that included recreational runners, only three defined "recreational runner". The studies of Noehren et al. (2013) and (2007) defined a recreational runner as one "who runs 20 miles or more per week which is equivalent to 32 km. Similarly Lun et al. (2004), states that a recreational runner is a runner who runs more than 20 km per week.

4.5 Outcome of interest: running-related injuries

4.5.1 Definition of running-related injuries

The definitions of "running-related injuries" among the studies showed some similarities and some differences. The studies all defined a running-related injury as a musculoskeletal injury resulting in a stoppage of participation in running. The differences in the respective studies rested in the specified time period of non-participation which varied among the studies. It can be assumed that the time period of non-participation on account of injury would be directly proportional to the severity of the injury.

Two studies defined a running-related injury as a musculoskeletal injury that causes a cessation of running or a decline in the frequency of running with no specification as to the length of the period. The injury had to be located on the lower limb (Eskofier et al., 2012; Lun et al., 2004). Hotta et al. (2015) defined a running-related injury as a musculoskeletal injury that caused a cessation in participation in running of at least four weeks. Beard (2015) defined running-related injury as a musculoskeletal injury that causes a change or a cessation in participation in running for a minimum of one training day. Similarly, Dudely et al. (2017) defined a running-related injury as a musculoskeletal injury of the lower extremities and back which causes a runner to be unable to train in one full training session. Bennell & Crossley, (1996) defined a running-related injury as an injury or pain which is musculoskeletal in origin and occurs during athletic training. To qualify for such a definition, the injury would have to result in a change in athletic training in some or other way for one

week or longer. The injuries in all studies were exclusive of acute or traumatic injuries. Two of the studies did not give a definition of "running-related injuries" (Noehren et al., 2013 & 2007).

4.5.2 Types of injuries

The majority of running-related injuries reported in the studies were patellofemoral pain (Dudley et al., 2017; Eskofier et al., 2012; Noehren et al., 2013, Lun et al., 2004; Bennell & Crossley, 1996), followed by iliotibial band syndrome (Noehren et al., 2007; Bennell & Crossley, 1996), and lastly, stress fractures (Dudley et al., 2017; Bennell & Crossley, 1996). In the study of Dudely et al. (2017), runners with running-related injuries were further diagnosed with patellar tendinosis (6.5%), strained gluteus maximus muscles (6.5%), strained quadriceps muscles (6.5%), and metatarsal fractures (2.9%). In two studies, some of the running-related injuries were self-reported and thus according to the anatomical site of the injury (Lun et al., 2004; Bennell & Crossley, 1996). The study of Beard, (2015) also reported injuries in terms of anatomical site instead of the specific diagnosis.

The most common site of injury in the study of Lun et al. (2004) was found to be the foot (15%), followed by the thigh (9%), and the lower leg (9%). Bennell and Crossley, (1996) reported similar results with the leg being mostly affected, followed by the knee, and the foot. In the study of Beard (2015), the knee joint and the ankle were the anatomical sites that were most affected by running-related injuries. One study did not supply the anatomical locations of any of the running-related injuries sustained (Hotta et al., 2015).

4.5.3 Diagnosis and reporting of injuries

In four of the eight of the included studies, the injuries sustained were assessed according to the most reliable method by means of diagnosis. A qualified medical practitioner such as a doctor, physiotherapist or a biokinetist diagnosed the injuries by means of validated clinical methods (Dudely et al., 2017; Eskofier et al., 2012; Noehren et al., 2013 & 2007). In two studies, running-related injuries were classified according to the body location affected by the injury, as well as the severity of the pain (Beard, 2015; Hotta et al., 2015). In these two studies, running-related injuries were reported using a

self-reporting method, whereby the athletes filled in questionnaires pertaining to the injuries sustained, such as location of the injury, and the onset and duration of the symptoms (Beard, 2015; Hotta et al., 2015). Self-reported injuries were found to be limited to the anatomical site of the injury since healthcare practitioners were not involved in the diagnosis of them. In two other studies, the injuries were diagnosed by clinicians and through the self-reporting method (Lun et al., 2004; Bennell & Crossley, 1996).

4.6 Exposure of interest: hip dysfunction

The exposure of interest in the eight studies was related to hip kinematics (Dudely et al., 2017; Beard, 2015; Noehren et al., 2013 & 2007; Lun et al., 2004; Bennell & Crossley, 1996), hip kinetics (Dudley et al., 2017; Beard, 2015; Eskofier et al., 2012; Noehren et al., 2007), measurements of the muscular strength of the hip (Beard, 2015) and functional movement (Hotta et al., 2015). The exposure of interests is depicted in the data extraction information in Table. 1.

The kinematic measurement that was found to be the most frequently investigated was the hip adduction angle (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013 & 2007). It was followed by the internal rotation angles of the hip (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013). Kinematic measurements of the peak adduction angles of the hip (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013 & 2007), hip abduction and the external (Beard, 2015) and internal rotation angles of the hip (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013), and the active and passive internal and external range of motion in the hip (Lun et al., 2004; Bennell & Crossley, 1996) were undertaken.

In all studies, the biomechanical running analysis was conducted on a runway with a force plate along the runway. In two of the studies, the participants ran at a self-selected pace (Dudley et al., 2017; Beard, 2015), while in the other studies, participants ran at a controlled speed, ranging from 3.7m/s to 4m/s (Noehren et al., 2013; Eskofier et al., 2012 & 2007).

The hip adduction angle was measured in the stance phase of running (Dudley et al., 2017; Beard, 2015; Noehren et al., 2013 & 2007). Only one study that applied the biomechanical method of analysis of running did not measure the hip adduction angle (Eskofier et al., 2012). The active and passive

internal and external range of motion and rotation angles of the hip were measured using an inclinometer (Lun et al., 2003). Different positions were assumed for the active and passive range of motion testing. The active range of motion of the hip was tested in a sitting position while the passive range of motion of the hip was tested in a prone position (Lun et al., 2003).

The investigated kinetic measurements of the hip included the following: the peak hip abduction moment (Beard et al., 2015; Noehren et al., 2013 & 2007; Eskofier et al., 2012), the hip adduction moment (Dudley et al., 2017; Eskofier et al., 2012), the internal rotation moment of the hip (Eskofier et al., 2012), the external rotation moment of the hip, and the extension and flexion moments of the hip (Beard, 2015; Eskofier et al., 2012). All the kinetic measurements were investigated on the basis of an instrumented biomechanical running analysis.

Beard, (2015) measured the maximum isometric contractions of the hip abductors, external rotators, extensors and flexors with a hand-held dynamometer (Nm/kg). The participants were positioned in supine for hip abduction, they lay in a prone position with the knee at 90 degrees for the external rotation and extension of the hip, and supine for hip flexion to 90 degrees (Beard, 2015).

Only one study included in this systematic review prospectively investigated hip dysfunction using functional measures, i.e. the Functional Movement screen tool[3] (Hotta et al., 2015). According to Cook et al. (2014), four tests, namely, the deep squat test, the hurdle test, the in-line lunge test, and the active straight leg raise test, are sufficient to test some function of the hip. The active straight leg raise test is used to screen hip control, pelvic stability and the flexibility of the gluteus maximus muscles. The deep squat test is used to screen the functional range of hip flexion; the hurdle step test is used to screen stride mechanics and stepping which are movements required for a normal biomechanical analysis of running; and the in-line lunge test is used to screen the stability, mobility, as well as abduction strength of the hip (Cook et al., 2014).

[3] a screening tool that can be used to assess stability, mobility and co-ordination of the body as the tests are performed.

Table 2. Data extraction table

Study	Critical appraisal rating	Study Design	Participants (age/ level of play/country)	Risk factor (exposure variable)	Injury definition (outcome)	Study results (factors associated) Confidence interval Risk ratio Effective size Standard deviation
"Pattern classification of kinematic and kinetic running data to distinguish gender, shod/barefoot and injury groups with feature ranking" (Eskofier et al., 2012)	10/11	Prospective cohort study	Germany 87 Recreational runners 44 Males 43 Females Mean age of 38 years Range (18-45	Hip flexion–extension moment Hip abduction-adduction moment Hip internal-external rotation moment	Injury is defined as any musculoskeletal symptom of the lower limb which requires a reduction or stoppage of normal training.	The Injury incidence per 1000 hours of running was 59%. Mean hip abduction moment may be an important indicator connected to the development of PFPS in runners. The mean hip abduction moments were significantly higher (p<0,001) for all six PFPS group patients.
"Relation between running injury and static lower limb alignment in recreational runners" (Lun et al., 2004)	9/11	Prospective cohort study	Canada 87 Recreational runners 44 Males 43 Females Mean age of 38 years Range (18-45)	Hip internal and external range of motion	An injury is defined as "any musculoskeletal symptom of the lower limb that requires a reduction or stoppage of normal training".	The injury incidence per 1000 hours of running was 59% (both sexes) 81 injuries were sustained. 17% of injuries that were diagnosed by the sports medicine doctor were PFP. 49% of injuries were new and 29% were re-occurrences, 22% unknown onset of injury. Location of injuries was identified only in 52% of runners. The most common injuries: foot (15%), thigh (9%), lower leg (9%). The findings of static lower limb biomechanical alignment were not found to be related to lower limb injury in recreational athletes.

Study	Critical appraisal rating	Study Design	Participants (age/ level of play/country)	Risk factor (exposure variable)	Injury definition (outcome)	Study results (factors associated) Confidence interval Risk ratio Effective size Standard deviation
"ABS clinical biomechanics award winner 2006 prospective study of the biomechanical factors associated with iliotibial band syndrome" (Noehren et al., 2007)	9/11	Prospective Cohort Study	United States of America 400 18 Female recreational runners Mean age of 26.8 years Range (18-45)	Hip adduction angle Hip abduction moment	No definition for running-related injury	Incidence rate of iliotibial band syndrome was 16%, 18 runners developed iliotibial band syndrome. The ITBS group visually landed in greater hip adduction and remained more adducted throughout the stance phase. The peak hip adduction angle was found to be significantly greater than that of the controls 14.1 (2.5) vs. control 10.6 (5.1) degrees (p=0.01). No difference in the hip abduction moment -1.4Nm (0.37) vs. control -1.3Nm (0.19) (p=0.56).
"Functional Movement screen for predicting running injuries in 18-24 year old competitive male runners." (Hotta et al., 2015)	10/11	Prospective Cohort Study	Tokyo , Japan 84 competitive athletes Mean age 20.0 SD (1.2) Range (18-24)	Functional Movement screen: Deep squat Hurdle step In line lunge Active straight leg raise	A running-related injury is defined as a musculoskeletal injury that 1) Occurs as a result of participating in practice or a race on track or field. 2) The injury or pain is sufficiently severe to prevent participation for at least four weeks.	17.9% of participants experienced running injuries during the season. Mean Functional Movement screen composite score was 13.3 ± 2.7 for injured participants and 14.4±2.2 for non-injured participants (p=0.07). Injured participants scored significantly lower on the deep squat and the active straight leg raise test (2.9±1.0) compared to non-injured participants (4.1 ±1.1) (p=0.010).

Study	Critical appraisal rating	Study Design	Participants (age/ level of play/country)	Risk factor (exposure variable)	Injury definition (outcome)	Study results (factors associated) Confidence interval Risk ratio Effective size Standard deviation
"Functional Movement screen for predicting running injuries in 18-24 year old competitive male runners." (Hotta et al., 2015)						The deep squat and the straight leg raise influenced the incidence of running injuries after adjusting characteristics (odds ratio= 9.7, 95% confidence interval= 2.1-44.4).
"Analysis of biomechanical and clinical factors influencing running related musculoskeletal injuries." Beard, (2015)	9/11	Prospective cohort study: Dissertation	United States of America 50 Female runners Mean age 39 , SD (±9)	Hip abduction angle Hip adduction angle Hip internal rotation angle Hip external rotation angle Hip abduction strength Hip external rotation strength Hip extension strength Hip flexion strength	A running-related injury is defined as "any chronic, running related, musculoskeletal injury of the lower extremity or back that results in the participant seeking out a clinician as a result of the following: 1) Modified or halted their running participation for at least one planned training day, including deviations in speed, time, or distance; or 2) Performed an alternate, less demanding activity in place of running for at least one planned, training day."	15 female runners sustained RRI (30%). 16% of injuries occurred at the knee. Runners who had sustained RRI had greater contralateral pelvic drop (1.44±0.08°) between 16%-28% of the stance phase than runners who remained injury-free. Between 48% and 93% of stance phase of running-injured participants had greater contralateral pelvic drop (1.64±0.12°). There were no significant changes in hip frontal and transverse plane movements during the stance phase. Hip isometric tests were not significantly different for the injured and pain-free runners. There was a weak association between peak contralateral pelvic drop and isometric hip abduction strength during the stance phase (r= 0.297 p= 0.036).

Study	Critical appraisal rating	Study Design	Participants (age/ level of play/country)	Risk factor (exposure variable)	Injury definition (outcome)	Study results (factors associated) Confidence interval Risk ratio Effective size Standard deviation
"Musculoskeletal injuries in track and field: incidence, distribution and risk factors" Bennell & Crossley, 1996	8/11	Retrospective Cohort study	Australia 19 athletes 9 Females 10 Males Club , state , national level distance runners Mean age of 20,3 , SD (2.0) Range (17-26)	Passive range of hip: external rotation, internal rotation flexion extension	An injury is defined as "any musculoskeletal pain or injury which results from athletic training and which is sufficient to cause an alteration in normal training in any way, mode, duration, intensity, frequency for a period of one week or more"	Injury exposure rate was 3, 9 per 1000 training hours. Distance runners sustained 95% overuse injuries and 5% acute injuries ($p<0.001$). The most common diagnosis was stress fractures (20.5%). The most common site for injury in long-distance runners was the knee.. There was no statistically significant difference between the injured and non-injured group in terms of biomechanical measures of the hip.
"Prospective evidence for a hip etiology in patellofemoral pain" (Noehren, Hamill & Davis, 2013)	9/11	Prospective Cohort Study	United States of America 400 Female Amateur runners Range (18 – 45) Total Mean age of 27 , SD (10)	Hip adduction angle Hip internal rotation angle	No definition of running-related injury	15 Participants were diagnosed with PFP. Runners who developed PFP had greater hip adduction than controls 12.1'2.8 vs. 8.1'4.5 ($p= 0.007$) respectively No significant differences were found for the hip internal rotation angle 4.5±5.2 vs. 3.0 ± 6.1 ($p=0.47$) respectively. Results suggest that runners who develop PFP use a different proximal neuromuscular control strategy than those who remain healthy.

Study	Critical appraisal rating	Study Design	Participants (age/ level of play/country)	Risk factor (exposure variable)	Injury definition (outcome)	Study results (factors associated) Confidence interval Risk ratio Effective size Standard deviation
"A prospective comparison of lower extremity kinematics and kinetics between injured and non-injured collegiate cross-country runners" (Dudley et al. 2017)	11/11	Prospective Cohort Study	United States of America 32 cross country runners Total Mean age (19.84)	Hip internal rotation angle Hip adduction angle Hip adduction moment	A running-related injury is defined as " any musculoskeletal complaint of the lower extremities or back causing restriction of participation in one full practice session." (Buist et al., 2010)	12 out of 31 runners sustained RRI. RRI occurred mostly at the knee (33.3%) and the shank (25.0%). Hip internal rotation for injured runners was 7.51 degrees and 4.80 for the non-injured runners (p=0.289). Peak hip adduction angle for the injured runners was 13.97 degrees and 12.66 for the non-injured runners (p=0.368). Peak hip adduction moment for the injured runners was 3.38 Nm/kg and 3.14 Nm/kg for the non-injured runners (p=0.401).

4.7 Narrative presentation of results

A meta-analysis of the results was not possible on account of the differences in the methodologies and the lack of studies investigating more than one exposure of interest. The results were therefore presented in a narrative form. Refer to the data extraction table, namely Table 1.

4.7.1 Kinematic hip measurements

The hip adduction angle during the stance phase of running in female long-distance runners was found to be associated with patellofemoral pain (p=0.007) (Noehren et al., 2013) and the iliotibial band syndrome (p=0.01) (Noehren et al., 2007) in two studies. In contrast, Dudley et al. (2017) found no statistical association between the hip adduction angle during the stance phase of running and running-related injuries. The study of Noehren et al. (2013) showed that female long-distance runners with patellofemoral pain presented with a larger hip adduction angle of 12.1 ± 2, 8 degrees vs. 8.1 ± 4.5 degrees for the controls (p=0.007). Female long-distance runners diagnosed with iliotibial band syndrome were also reported to have a larger hip adduction angle than their controls 14.1 ± 2.5 degrees vs. 10.6 ± 5.1) degrees respectively (p=0.01) (Noehren et al., 2007). On the other hand, Dudley et al. (2017) reported a hip adduction angle of 13.97 degrees in injured runners vs. 12.66 degrees in the non-injured runners (p= 0.366), indicating no association between the hip adduction angle and running-related injuries.

The internal rotation angle of the hip (Dudley et al., 2017; Noehren et al., 2013; Beard, 2015), and the hip abduction and external rotation angles (Beard, 2015) during the stance phase of running were not statistically associated with running-related injuries. Dudley et al. (2017) reported that runners who had sustained running-related injuries had an internal rotation angle of the hip of 7.51 degrees vs. the 4.80 degrees of the controls (p=0.289). The runners who sustained running-related injuries had a greater internal rotation angle of the hip during the stance phase of running than was the case with the controls. This was supported by Noehren et al. (2013), who reported a larger internal rotation angle

of the hip in runners with patellofemoral pain of 4.5 ± 5.2 degrees vs. 3.0 ± 6.1 (p=0.47) for the controls. Although there was a difference in the internal rotation angle of the hip between runners who were injured and those who remained injury-free, the results were not statistically significant. The hip abduction angle during the stance phase of running was also not associated with running-related injuries (Beard, 2015).

Static measurements of the hip such as the active and passive range of motion angles of the internal and external rotators of the hip were investigated in two studies (Lun et al., 2004; Bennell & Crossley, 1996). In the study of Lun et al. (2004), the active range of motion of the hip was measured with the runners sitting on the edge of a plinth with their feet suspended. Injured runners had lower active internal and external rotation angles of the hip on the left side as opposed to the same side of the non-injured runners. Injured runners had active internal rotation angles of the hip of 33.85 ± 7.69 degrees vs. 36.56 ±7.91 degrees and active external rotation angles of the hip of 39.43 ± 9.36 degrees vs. 41.00 ± 9.31 degrees for non-injured athletes (Lun et al., 2004).

Active external rotation angles of the hip on the right side were larger in the injured runners as opposed to those in the non-injured runners, and active internal rotation angles of the hip were smaller in the injured runners than in the non-injured runners. The active external rotation angle of the hip on the right side of the injured runners was 43.82 ± 54.26 degrees vs. 37.56 ± 9.36 degrees of the non-injured runners and the active internal rotation angles of the hip were 35.28 ± 9.49 degrees in the injured runners vs. 42.11 ±8.81 degrees in the non-injured runners respectively (Lun et al., 2004). Active internal and external rotation angles of the hip in injured runners were found not to be statistically associated with running-related injuries and the difference between the range of motion angles of the hips of the injured and non-injured runners was not statistically significant.

Similar results were found in the study of Bennell & Crossley, (1996), where passive internal and external rotation range of motion angles of the hip were measured in the prone position with the knee in 90 degrees of flexion. The specific passive rotation angles of the hip that were actually measured were not provided in the study (Bennell & Crossley, 1996). Active and passive internal and external rotation angles of the hip were not associated with running-related injuries (Lun et al., 2004; Bennell & Crossley, 1996).

4.7.2 Kinetic hip measurements

Hip abduction moment was the most frequently studied kinetic measure of the hip (Eskofier et al., 2012; Beard, 2015; Noehren 2007). In the study of Beard (2015), injured female runners had hip abduction moments of 1.13 ±0.32 Nm vs. l 1.19 ±0.25 Nm of the controls (p= 0.550). The study of Noehren et al. (2007) reported hip abduction moments in runners with iliotibial band syndrome of 1.4 ± 0.37 Nm vs. -1.3 ± 0.19 of the control (p=0.56). In both studies, the results were not significantly different between the injured and the non-injured runners.

In contrast, Eskofier et al. (2012) reported that hip abduction moment for injured runners was statistically greater than that for the non-injured participants ($p<0.001$). The results of the study by Eskofier et al. (2012) were interpreted with caution owing to the high dropout rate and inadequate follow-up on the participants in the study. Initially, there were 157 participants in the study; 73 (49%) dropped out and 49 (31%) were not followed up on (Eskofier et al., 2012).

Hip adduction moment in the stance phase of running is not generally associated with running-related injuries in runners (Dudley et al., 2017; Eskofier et al., 2012). Dudley et al. (2017) reported that non-injured runners had hip adduction moments of 3.38 Nm/kg vs. the 3.13 Nm/kg hip adduction moments of the controls (p=0.401). There was not much difference between the adduction moments of the injured and the non-injured runners. Hip flexion moments, and internal and external rotation moments in the stance phase of running were not associated with running-related injuries and were only investigated in one study (Eskofier et al., 2012).

4.7.3 Muscular hip measurements

Only one study investigated the association of hip muscle strength with running-related injuries (Beard, 2015). Hip muscle strength was measured with a hand-held dynamometer. The muscles that were tested included the hip abductors, external rotators, extensors and flexors. The isometric muscle strength of these muscles was not indicative of a higher risk of running-related injuries. Hip abduction strength in runners who had sustained running-related injuries was 1.13 ± 0.32 (Nm/kg) vs. 1.29 ±

0.25 (Nm/kg) (p=0.550) of the controls (Beard, 2015). The external rotation strength of the hips in the injured runners was found to be 0.47 ± 0.07 (Nm/kg) vs. 0.49 ± 0.08 (Nm/kg) (p=0.392) of the controls, and the hip extension was 0.71 ± 0.14 (Nm/kg) vs. 0.70 ± 0.20 (Nm/kg) (p=0.741) respectively. The external rotation of the hip and the extension strength of the injured and non-injured runners were similar and not associated with running-related injuries. The hip flexion strength of the injured runners was 0.79 ± 0.14 (Nm/kg) vs. 0.76 ± 0.17 (Nm/kg) (p=0.494) of the controls which was also similar (Beard, 2015).

The Cohen's d-effect sizes for all muscle strength values were below 0.2, indicating a very small difference between the injured and non-injured runners. The muscle strength of the hip abductors, external rotators, extensors and flexors was not associated with running-related injuries (Beard, 2015).

4.7.4 Functional hip measurements

The study of Hotta et al. (2015) is the only study that investigated hip dysfunction using functional measurements and researched male runners only. The Functional Movement screen test was used and four tests were identified as appropriate for screening hip dysfunction (Cook et al., 2014). The four tests included the active straight leg raise test, the deep squat test, the in-line lunge test, and the hurdle step test. The in-line lunge test (p= 0.26) and the hurdle step test (p=0.20) were not associated with an increased risk of running-related injuries. However, only the results of the active straight leg raise test and the deep squat test were associated with running-related injuries (p<0.01) and (p=0.01) respectively. The results of the deep squat test through further scrutiny were excluded from the results of this systematic review due to other key kinetic chain components that are required to be able to perform the test functionally. To perform the deep squat test one would be required to perform the following movements in a closed kinetic chain: bilateral ankle dorsiflexion, bilateral hip and knee flexion, extension of thoracic spine and bilateral flexion and abduction of the shoulders (Cook et al., 2014).

The maximum score for one test that a runner could score was a three; that was recorded if the runner completed the test perfectly. A score of two was awarded if the runner compensated while performing the test; a score of one was aw3arded if the test was not completed correctly, and zero, if pain was felt

during the test. A total of 15/84 runners sustained running-related injuries of which 11/15 (73%) scored three or less than three for the deep squat and active straight leg raise tests. Only 4/15 (27%) scored four or more than four for the deep squat and active straight leg raise tests.

The active straight leg raise test was associated with running-related injuries tested in a univariate analysis ($p<0.01$). It was therefore found that injured runners who scored 2.9 ± 1.0 vs. 4.1 ± 1.1 ($p<0.01$) on the active straight leg raise were more susceptible to running-related injuries. Furthermore, runners who scored three or less than three on the active straight leg raise test were more susceptible to running-related injuries (OR = 9.7 95% CI = 2.1-44.4, $p=0.01$). The 73% of injured runners had a composite score of ≤ 14 and the remaining 27% had a score of ≥ 15. The composite score of the Functional Movement screen for the injured runners was 13.3 ± 2.7 vs. 14.4 ± 2.2 for the non-injured runners. This difference was found to have no statistical significance ($p=0.07$) (Hotta et al., 2015).

4.8 Conclusion of results

Out of the eight studies included in the systematic review, four studies reported an association between hip dysfunction and running-related injuries. A greater hip adduction angle was found to be associated with patellofemoral pain ($p=0.007$) (Noehren et al., 2013) and iliotibial band syndrome ($p=0.01$) (Noehren et al., 2007) in female long-distance runners during the stance phase of running. Hip abduction moments for injured runners were statistically greater than those for non-injured participants ($p<0.001$), Eskofier et al. (2012). However, the results of the study by Eskofier et al. (2012) should be interpreted with caution on account of the high dropout rate and inadequate follow-up investigations in the study. The active straight leg raise test ($p<0.01$) was found to be predictive of running-related injuries in competitive male long-distance runners (Hotta et al., 2015).

Chapter 5: Discussion

5.1 Introduction

The objective of the systematic review was to assess the association between hip dysfunction and lower limb running-related injuries in long-distance runners. Eight studies were included in this review in order to judge whether runners with hip dysfunction are at a higher risk of developing running-related injuries. An increased hip adduction angle and the active straight leg raise test were associated with running-related injuries (Hotta et al., 2015; Noehren et al., 2013, 2007;).

The systematic review included studies where participants were followed prospectively over time in order to monitor the incidence of running-related injuries. These types of studies are of great value when completed with high quality methods. These studies also enabled the researchers to analyse the association between the variable of interest, in this case, hip dysfunction, and the outcome, namely running-related injuries.

5.2 Kinematic hip measurements

5.2.1 Hip adduction angle and patellofemoral pain

The evidence in one good study supports the supposition that a greater hip adduction angle is a risk factor in developing patellofemoral pain ($p= 0.007$) in female runners (Noehren et al., 2013). The results suggest that female long-distance runners with large hip adduction angles are susceptible to running-related injuries, namely patellofemoral pain. Healthy females are known to exhibit different frontal plane biomechanics as opposed to men, and more specifically in terms of a larger hip adduction angle during running (Sugimoto et al., 2014; Nakagawa et al., 2012). The same results were found when female runners with patellofemoral pain were compared to healthy matched controls in a cross-sectional study (Noehren et al., 2012). The results of both the prospective (Noehren et al., 2013) and cross-sectional (Noehren et al., 2012) studies indicate that females may be susceptible to patellofemoral pain because of the different biomechanics that they exhibit as opposed to those exhibited by males.

The reason for this difference was thought to be due to a deficit in the muscular strength of the hip abductor, because, the hip abductors function to abduct the hip. This reasoning, that the hip adduction angle increases as a result of abduction weakness in the hip, is not supported by sufficient evidence but is inclined rather to be refuted statistically (Baggaley et al., 2015). However, Thijs et al. (2011) reported that isometric muscular strength of the hip abductor is not a risk factor for patellofemoral pain. Baggaley et al. (2015) reported parallel results in the lack of association that they found between hip abduction strength and frontal plane kinematics. Both static and dynamic studies do not support this theory. This is elaborated on in Section 5.3.

5.2.2 Hip adduction angle and iliotibial band syndrome

Female runners with no history of running-related injuries and larger hip adduction angles during running have an increased risk of developing iliotibial band syndrome (Noehren et al., 2007). Ferber et al. (2010) reported similar results in a cross-sectional study. A larger hip adduction angle during running may contribute to changes in the knee joint and the lower limb that render female long-distance runners more susceptible to iliotibial band syndrome. A larger hip adduction angle may be associated with a larger knee abduction angle during running (Sakaguchi et al., 2014). Increased knee abduction may occur as a compensatory mechanism for the increased hip adduction in order to re-align the lower limb to a neutral position (Brukner & Khan, 2012).

Female runners previously suffering from iliotibial band syndrome, and those with current iliotibial syndrome, present with different biomechanics in running (Foch et al., 2015). Runners with a history of iliotibial band syndrome have smaller hip adduction angles as opposed to those with current iliotibial band syndrome and their healthy controls (Foch et al., 2015). It would seem that the size of the hip adduction angle may decrease on account of the runner compensating for the lateral knee pain caused by iliotibial band syndrome (Brukner & Khan, 2012). In contrast to the studies of Noehren et al. (2013) & (2007), Dudley et al. (2017) found no association between the size of the hip adduction angle and running-related injuries. The study of Dudley et al. (2017) included both male and female participants and the size of the hip adduction angle was reported collectively for all runners who had sustained running-related injuries irrespective of the diagnoses or gender. This could have played a role in the disparities in the results among the studies.

5.2.3 Internal and external rotation of the hip

The internal rotation of the hip, measured by the passive range of motion, was investigated in two studies (Lun et al., 2004; Bennell & Crossley, 1996). There was no significant correlation with running-related injuries. The internal rotation angle of the hip measured by means of an instrumented running analysis on a runway was also not statistically associated with running-related injuries - even when investigated specifically in female runners with patellofemoral pain (Noehren et al., 2013) and iliotibial band syndrome (Noehren et al., 2007). Hip internal rotation may not be associated with running-related injuries but in more recent studies it was found that, when compared to males, healthy females presented with a larger internal rotation angle of the hip *(*p=0.001) during an instrumented running analysis (Hanningan et al., 2018; Sakaguchi et al., 2014).

Raissi et al. (2009) similarly reported that the internal rotation of the hip is not a risk factor for developing medial tibial stress syndrome but the outcome of interest in the study by Raissi et al. (2009) was medial tibial stress syndrome and not related to running-related injuries. Noehren et al. (2012 & 2013) reported that females with patellofemoral pain and iliotibial band syndrome exhibit larger internal rotation angles of the hip than their matched controls, which suggests that they may exhibit larger internal rotation angles of the hip as a result of patellofemoral pain (Noehren et al., 2013) or iliotibial band syndrome (Noehren et al., 2007). Therefore, internal rotation of the hip may be a potential compensatory mechanism in female runners with patellofemoral pain (Noehren et al., 2013) and iliotibial band syndrome (Noehren et al., 2007). It was also found that, when compared to males, healthy females presented with a larger internal rotation angle of the hip *(*p=0.05) during running (Sakaguchi et al., 2014).

5.3 Kinetic hip measurements

5.3.1 Hip abduction strength

One of the studies covered by the systematic review found no association between static hip abduction strength and running-related injuries (Beard, 2015). Baggaley et al. (2015) supported these results that there was no association between the isometric muscular strength of the hip abductors and the hip

adduction angle in female runners during running. Furthermore isometric hip abduction strength could be associated with deviations in the neck shaft angle of the femur. However, it was found that the femoral shaft angle was not associated with the hip adduction angle during running (Baggaley et al., 2015). Hip abduction strength measured by an instrumented running analysis in healthy male and female runner yielded similar results to static measurements. There was no significant difference of hip abduction strength between male and female runners (p=.759) (Hannigan et al., 2018).

A greater eccentric hip abduction strength is a statistically significant factor for reducing the development of patellofemoral pain in novice runners during the first 50 km of a running programme (p<.05) (Ramskov et al., 2015). Gender differences of hip eccentric strength between healthy male and female novice runners exist. Female runners have a lower maximal eccentric hip abduction torque than males (Ramskov et al., 2015). Baggaley et al. (2017) conversely reported no association between eccentric hip abduction strength and hip kinematics in male recreational runners. This was further supported by Brund et al. (2015) who found no association between eccentric hip abduction strength , patellofemoral pain and iliotibial band syndrome in recreational male runners. Gender differences already discovered between males and females, could have influenced the results of the studies.

The relationship between eccentric hip abduction strength and lower limb kinematics in males and females warrants further investigation. The results of this systematic review are supported by those of cross-sectional studies completed on hip muscle strength in runners (Esculier et al., 2015; Herbst et al., 2015; Boling et al., 2013).

5.3.2 Hip abduction moment

One study of fair quality in this systematic review found a higher hip abduction moment to be a risk factor in developing running-related injuries in long-distance runners (Eskofier et al., 2012). This was contrary to the results of Beard, (2015) and Noehren et al. (2007), who both found that the hip abduction moment during the stance phase of running is not associated with running-related injuries in female long-distance runners. In the study by Eskofier et al. (2012), 50% of the injured runners were found to be male and 50%, female. The study of Eskofier et al. (2012) had limitations, though,

namely the large number of participants that dropped out of the study, and the lack of follow-up of the participants, which means that the results would have to be used with caution.

Running is a dynamic sport and thus Taylor-Haas et al. (2014) investigated the isokinetic hip strength in male long-distance runners. Peak isokinetic hip abduction torque was found to be inversely associated with hip adduction and abduction range of motion (Taylor-Haas et al., 2014). This means that a larger hip abduction torque tends to be associated with a smaller hip adduction angle in the participants during long-distance running. Furthermore, it was reported that females may have lower hip abduction peak torques as opposed to males ($p=0.03$) (Sugimoto et al., 2014).

It is postulated that muscle activation properties, and compensatory mechanisms such as ipsilateral lean and gender, may contribute to differences in kinetics and kinematics during running (Ferber et al., 2011). When compared to male runners, female runners have higher peak gluteus maximus activation, a higher average activation level and a larger adduction angle of the hip during running. The consequences of higher activation of the gluteus maximus muscles could be fatigue that occurs earlier in females than in males, thus predisposing them to abnormal running kinematics of the lower extremity that are linked to injury (Willson et al., 2012).

Similarly Reynolds et al. (2016) found that, as opposed to male runners, female recreational runners present with reduced activation of the gluteus medius and higher activation levels of gluteus maximus, rectus femoris and tensor fascia latae. Furthermore, the female runners presented with higher activation levels than male runners when it came to all of the above-mentioned muscles except for the gluteus medius. Electromyographical investigations are recommended in attempt to explain these discrepancies in muscular activation (Reynolds et al., 2016; Willson et al., 2013).

The results of this systematic review indicate that a larger hip adduction angle is associated with running-related injuries. The link between long-distance runners with lower/higher hip abduction peak torque, and larger/smaller hip adduction and abduction angles, should be investigated further. A larger hip abduction moment may be associated with running-related injuries in long-distance runners (Eskofier et al., 2012).

5.4 Functional hip measurements

The Functional Movement screen tool (Cook et al., 2014) is composed of seven tests, namely, the deep squat, the in-line lunge, the active straight leg raise, rotatory stability, the hurdle step, shoulder mobility, and the trunk stability push-up. Hotta et al. (2015) found that competitive male long-distance runners with poor scores on the active straight leg raise test are at risk of sustaining running-related injuries. The active straight leg raise test has proved to be more specific in screening for the risk of running-related injuries than the composite score of the Functional Movement screen tool (Hotta et al., 2015). It was found that the overall composite test of the Functional Movement screen tool is not associated with predicting running-related injuries even though the injured runners tended to score lower on the test (Hotta et al., 2015).

Several studies have reported on the lack of association between the overall composite score of the Functional Movement screen tool and the prediction of injuries throughout different sporting populations (Moran et al., 2017; Mokha et al., 2016). The individual test score results of Hotta et al. (2015) correlate with those of Mokha et al. (2016) in which individual scores for the Functional movement screen tool proved to be predictive of injuries in athletes rather than runners. This highlights the importance of using the Functional Movement screen tool in sport-specific populations on account of the uniqueness of each sport and the specialised movements that each sport involves (Cook et al., 2014).

In order to perform the active straight leg raise test accurately, one requires flexibility of the hamstrings, the gluteus maximus and the iliotibial band (Cook et al., 2014). When the lower limb is raised, the athlete needs to be able to dissociate the lower limb from the trunk, and to stabilise the pelvis and opposite hip for a smooth movement to take place (Cook et al., 2014). The ability to dissociate the lower limbs from the trunk and to flex the hip with a stabilised pelvis is also required for a normal biomechanical run in long-distance runners.

The results of Hotta et al. (2015) on the active straight leg raise test are encouraging and suggest that the test may be used in screening for heightened risk of running-related injuries in male long-distance

runners. The Functional Movement screen tool warrants further investigation in respect of prospective studies on female long-distance runners.

5.5 Exposure of interest

The association between hip dysfunction and running-related injuries is one that has been researched over the years under different types of study design; in retrospective studies (Bennell & Crossley, 1996), descriptive laboratory studies (Teng & Powers, 2016) and other prospective studies not included in this systematic review since they do not meet the inclusion criteria (Greybe, 2015; Ramskov et al., 2015; Hein et al., 2014; Thijs et al., 2011; Buist et al., 2010; Wen et al., 1998**).**

The hip dysfunction components investigated in similar studies on running-related injuries were found to vary from the internal rotation range of motion of the hip to its external rotation range of motion (Buist et al., 2010), isometric hip muscle strength (Thijs et al., 2011; Hein et al., 2014), eccentric hip abduction strength (Ramskov et al., 2015), hip kinematic measures through biomechanical running analysis (Hein et al., 2014). The components investigated in similar studies correlated with those investigated in our study.

The testing position and the manner in which measurements are taken when investigating kinetic and kinematic factors impact on the outcome of these measurements. The differences in measuring hip dysfunction components render it almost impossible to compare the results of the studies owing to subtle differences that might have occurred. Thus it is important for researchers to be as specific as possible in describing how measurements were taken, not only to account for accuracy but also for them to be duplicated by future researchers.

The use of different instruments to measure the range of motion of the hip is featured in different studies (Buist et al., 2010; Lun et al., 2003). Lun et al. (2003) tested hip range of motion with an inclinometer and Buist et al. (2010) used a goniometer. Although the inclinometer and the goniometer are both reliable instruments for measuring range of motion, comparisons between studies using these two devices have been cautioned against due to differences of between three to five degrees found in

all hip ranges of motion when using the different instruments (Roach et al., 2013; Bierma-Zeinstra et al., 1998).

To consider hip dysfunction as a risk factor for running-related injuries, hip dysfunction would have to be present prior to the occurrence of the running-related injury because the dsyfunction that a running-related injury causes in the hip does not automatically mean that it will result in a running-related injury in a healthy runner. This highlights the significance of prospective cohort studies and the systematic reviews thereof.

5.6 Definitions of types of runners

Similar prospective studies that were conducted with the aim of discovering the association between hip dysfunctional factors and running-related injuries have been completed (Greybe, 2015; Ramskov et al., 2015; Hein et al., 2014; Thijs et al., 2011; Buist et al., 2010; Wen et al., 1998). The difference between these studies and those included in this systematic review is the distance per week that the participants ran. The participants of the aforementioned studies ran less than the distance required to be included in this study.

The majority of the runners were novice runners (Greybe, 2015; Ramskov et al, 2015; Thijs et al., 2011; Buist et al., 2010), followed by recreational runners (Hein et al., 2014; Wen et al., 1998). Novice runners have no prior experience of running and thus would not be able to acquire a running distance of 32 km per week as per our inclusion criteria (Kluitenberg et al., 2015). Recreational runners, on the other hand, are eligible to do so. This correlates with the majority of recreational runners who were participants in the studies included in this systematic review. It appears that conducting prospective cohort studies in runners is more feasible in novice and recreational runners.

Acquiring participants for prospective studies is challenging and it seems, amongst other factors, that when studies are not only result-oriented, but also participant goal-oriented, the numbers of participants increase as well as follow through for the entire course of the study.

5.7 Study characteristics

The majority of the studies that were included in the systematic review were prospective cohort studies. Prospective cohort studies in this systematic review had the advantage of facilitating the discovery of risk factors for hip dysfunction associated with running-related injuries.

The mean age of the participants in similar studies was found to be 39.3 years, which differs by 10.7 years from the 28.6 mean age of the participants reported in this systematic review (Greybe, 2015; Ramskov et al., 2015; Hein et al., 2014; Thijs et al., 2011; Buist et al., 2010; Wen et al., 1998). As mentioned previously, the main difference between the studies included in this systematic review and these particular studies is the type of runners included. The higher mean age of novice runners reported in similar studies may indicate that recreational runners participating in prospective studies are younger than novice runners doing the same. The association between age and injuries in participants included in this study did not feature as a factor of interest.

The follow-up time in the studies included in this systematic review ranged from 14 weeks to 24 months. It is the opinion of the author that shorter follow-up periods may not allow sufficient time for injuries to occur and thus may result in researchers concluding on the outcomes prematurely and missing other important results that could have surfaced at a later stage had the follow-up time been longer. The follow-up time in similar prospective studies ranged from eight weeks to 12 months (Greybe, 2015; Ramskov et al., 2015; Hein et al., 2014; Thijs et al., 2011; Buist et al., 2010; Wen et al., 1998). To date, the author of this systematic review is not aware of any literature on follow-up times in prospective studies on long-distance runners.

5.8 Types of injuries

There is an extensive amount of research that has been completed on patellofemoral pain in runners (Almeida et al., 2016; Esculier et al., 2015; Barton et al., 2013; Noehren et al., 2012; Dierks et al., 2011). Patellofemoral pain was also the most common running-related injury in the studies included in this systematic review (Dudley et al., 2017; Eskofier et al., 2012; Noehren et al., 2013, Lun et al., 2004; Bennell & Crossley, 1996). The increased interest in patellofemoral pain may be due to the

multifactorial etiological nature of the injury and thus the ongoing search for causes and risk factors associated with the injury. This correlates with the incidence of patellofemoral pain found in the studies included in our systematic review. Iliotibial band syndrome was found to be the second-most-reported running-related injury that affected runners.

Patellofemoral pain and iliotibial band syndrome both primarily affect the knee joint, which was found to be the most affected joint in our systematic review in instances where participants reported injuries by means of questionnaires. Similar results of the knee being the most affected area in the body were observed in the studies of Greybe, (2015) and Wen et al., (1998).

5.10 Limitations of studies

The methodological quality of the prospective literature was, on average, high. On account of differences in measuring the outcome of interest and the definition of 'running-related' injury, the results in some studies could not be pooled into a meta-analysis, and therefore resulted in a narrative analysis of the results. Two studies had a high dropout rate and poor follow-up investigations into participants (Eskofier et al., 2012; Lun et al., 2004).

Chapter 6: Conclusions

6.1 Conclusion of systematic review

The objective of the systematic review was to assess the association between hip dysfunction and lower limb injuries in long-distance runners. The systematic review established an association between an increased hip adduction angle during the stance phase of running and lower limb injuries in female runners. Running-related injuries found to be associated with larger hip adduction angles were patellofemoral pain and iliotibial band syndrome in female long-distance runners. The active straight leg raise from the Functional Movement screen tool was predictive of running-related injuries in male competitive runners. The risk of hip internal and external rotation, isometric hip muscle strength as factors to developing running-related injuries was not established.

6.2 Implications for practice

Hip adduction angle-reducing strategies may be incorporated into injury-prevention programmes for female long-distance runners to prevent running-related injuries, namely patellofemoral pain and iliotibial band syndrome.

Male long-distance competitive runners, may be additionally screened using the active straight leg raise test of the Functional Movement screen tool as one of the screening tools to predict injury.

6.3 Recommendations for future research

Running-related injuries are common in runners and it is, therefore, recommended that prospective studies are dedicated to this group of athletes. Running injuries are often non-traumatic, develop over time and generally arise from overuse (Brukner & Khan, 2012). The uniqueness of the aetiology of these injuries warrants special attention to be given to injury-prevention strategies to prevent excessive hip adduction in female runners. It is also recommended that instead of being self-reported, the running-related injuries reported in the studies should be diagnosed by health-care professionals in

order to analyse injury-specific aetiologies. The majority of the studies investigated hip dysfunction in solely males or females, so the results could not be generalised to both genders. Thus, it is recommended that injury-specific studies include participants of both genders and that the presentation of results be presented for both genders as a whole, and also separately, to compare any differences and to view any uniqueness between the two genders. Based on the results of this study, the development of gender-specific strategies to prevent excessive hip adduction in running is recommended to prevent patellofemoral pain and iliotibial band syndrome in female runners.

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8. Appendices

Appendix I:JBI critical appraisal checklist for comparable cohort/case control studies

Reviewer_____Date _____

Author_____Year_____Record Number

	Yes	No	Unclear
1. Is the sample representative of patients in the population as a whole?			
2. Are the patients at a similar point in the course of their condition/illness?			
3. Has bias been minimized in relation to selection of cases and of controls?			
4. Have confounding factors been identified and are the strategies put in place to deal with them stated?			
5. Are outcomes assessed using objective criteria?			
6. Was follow-up carried out over a long enough time period?			
7. Were the outcomes of people who withdrew from the research described and included in the analysis?			
8. Were outcomes measured in a reliable way?			
9. Were appropriate statistical analysis tests used?			

Overall appraisal: ☐ Include ☐ Exclude ☐ Seek further info

Comments (including reasons for exclusion):_____

_____

_____

_____

Appendix II: JBI data extraction form for experimental/observational studies

Reviewer _____ Date _____
Author _____ Year _____
Journal _____ Record Number _____

Study Method RCT ☐ Quasi-RCT ☐ Longitudinal ☐
Retrospective ☐ Observational ☐ Other ☐

Participant
Setting _____
Population _____
Sample size
Intervention 1_____ Intervention 2_____ Intervention 3 _____

Interventions

Intervention 1: _____
_____
Intervention 2: _____
_____

Intervention 3: _____
_____

Clinical outcome measures

Outcome Description	Scale/measure

Study results

Dichotomous data

Outcome	Intervention ( ) number / total number	Intervention ( ) number / total number

Continuous data

Outcome	Intervention ( ) mean & SD	Intervention ( ) mean & SD

Authors' conclusions: ____

_____

Comments: _____

_____

Appendix III: List of excluded studies

Based on a review of the full text content, the following studies were excluded:

	Author and Year	Title of Article	Reason for exclusion
1.	Pohl et al. (2008)	Biomechanical predictors of retrospective tibial stress fractures in runners	Participants not injury-free at start of study
2.	Hölmich, P (2007)	Long-standing groin pain in sportspeople falls into three primary patterns: a "clinical entity" approach: a prospective study of 207 patients.	Participants not pain-free at start of study
3.	Cabri & Marmeleira (2003)	Athletic injuries in middle-distance and long-distance runners	German Article Exposure of interest not hip dysfunction http://europepmc.org/abstract/med/12892067
4.	Ross & Schuster (1983)	A preliminary report on predicting injuries in distance runners	Exposure of interest not hip dysfunction
5.	Wen, Puffer & Schmalzried (1997)	Lower extremity alignment and risk of overuse injuries in runners. / Alignement des extremites des membres inferieurs et risque de blessures lies au surentrainement chez des coureurs a pied.	Exposure of interest not hip dysfunction
6.	Luedke et al. (2015)	Association of isometric strength of hip and knee muscles with risk of injury in high school cross-country runners.	Participants younger than 18 years

7.	Duckham et al. (2015)	Stress fracture injury in female endurance athletes in the United Kingdom: A 12-month prospective study	Hip dysfunction not exposure of interest
8.	Davis, Bowser & Mullineaux (2016)	Greater vertical impact loading in female runners with medically-diagnosed injuries: a prospective investigation	Hip dysfunction not exposure of interest
9.	Teng & Powers (2016)	Hip-extensor strength, trunk posture, and use of the knee-extensor muscles during running	Descriptive laboratory study. Runners were not long-distance runners and were not followed up for a period of time
10.	Poppel et al. (2016)	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	Hip dysfunction not exposure of interest
11.	van Middlekoop et al. (2007)	Risk factors for lower extremity injuries among male marathon runners	Hip dysfunction not exposure of interest
12.	Proft et al. (2016)	The influence of long distance running on sonographic joint and tendon pathology: results from a prospective study of marathon runners	Hip dysfunction not exposure of interest
13.	van der Worp et al. (2012)	The five-or 10-km Marikenloop Run: a prospective study of the etiology of running- related injuries in women	Hip dysfunction not exposure of interest

14.	Van Poppel et al. (2016)	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	Hip dysfunction not exposure of interest
15.	Stefanyshyn et al. (2015)	Knee-joint moments and patellofemoral pain syndrome in runners. Part 1: a case control study; Part 2: a prospective cohort study	Hip dysfunction not exposure of interest
16.	Raissi et al. 2009	The relationship between lower extremity alignment and Medial Tibial Stress Syndrome among non-professional athlete**s**	Participants not runners
17.	Wen et al. 1998	Injuries in runners: a prospective study of alignment	Runners ran less than 32 km per week Hip dysfunction not exposure of interest
18.	Hein et al. 2014	A prospective analysis of intrinsic and extrinsic risk factors on the development of Achilles tendon pain in runners	Runners ran less than 32 km per week.
19.	Buist et al. 2010	Predictors of running-related injuries in novice runners enrolled in a systematic training program	Runners ran less than 32 km per week
20.	Ramskov et al. 2013	No association between q-angle and foot posture with running-related injuries: a 10-week prospective follow-up study	Hip dysfunction not exposure of interest

21.	Ramskov et al. 2015	High eccentric hip abduction strength reduces the risk of developing patellofemoral pain among novice runners initiating a self-structured running programme: a one- year observational study	Runners ran less than 32 km per week
22.	Hespanhol et al. 2015	Lower limb alignment characteristics are not associated with running injuries in runners: A prospective cohort study	Hip dysfunction not exposure of interest
23.	Thijs et al. 2011	Is hip muscle weakness a predisposing factor for patellofemoral pain in female novice runners?	Runners ran less than 32 km per week.
24.	Buist et al 2009	Predictors of running-related injuries in novice runners enrolled in a systematic training program	Runners ran less than 32 km per week.
25.	Greybe et al. 2015	Risk factors for lower limb musculoskeletal injuries in novice runners: a prospective study	Runners ran less than 32 km per week.
26.	Taunton et al. 2002	A prospective study of running injuries: the Vancouver Sun Run "In Training " clinics	Hip dysfunction not exposure of interest
27.	Paquette & Melcher 2017	Impact of a Long Run and injury-related biomechanics with relation to weekly mileage in trained male runners	Participants participated in two laboratory examinations. No follow-up Running-related injuries were not outcomes of interest

28.	Altman & Davis 2016	Prospective comparison of running injuries between shod and barefoot runners	Hip dysfunction not exposure of interest
29.	Bredeweg & Kluitenberg 2013	Differences in kinetic asymmetry between injured and non injured novice runners: A prospective cohort study	Hip dysfunction not exposure of interest
30.	Bredeweg & Kluitenberg 2013	Differences in kinetic variables between injured and noninjured novice runners: A prospective cohort study	Hip dysfunction not exposure of interest
31.	Joslin & Bodin 2016	The functional movement screen and injury prevalence in collegiate athletes	No long-distance runners as participants
32.	Appel 2012	The capability of the functional movement screen to predict injury in Division I male and female track and field athletes	The runners were not followed up for a period of time
33.	McMullen 2013	Injury prediction in Division I collegiate cross-country runners using functional-movement tests	Dependent variable was not lower limb injuries The aim of the study was to see if there was a difference in the FMS before and after a simulated workout state in runners
34.	Garrison, Westrick & Benenson 2015	Association between the functional- movement screen and injury development in college athletes	No long distance runners
35.	Abal et al., 2013	Injury risk factors for runners	Runners ran less than 32 km per week.

Appendix V: Ethical waiver

Human Research Ethics Committee (Medical)

Research Office Secretariat: Senate House Room SH10005, 10th floor. Tel +27 (0)11-717-1252
Medical School Secretariat: P V Tobias Health Sciences Building, 2rd floor
Tel +27 (0)11-717-2700 / 1234 / 1252 / 2656
Private Bag 3, Wits 2050, www.wits.ac.za. Fax +27 (0)11-717-1265
South African National Health Research Ethics Council registration: REC-250208-04
United States Office of Human Research Protections registration: FWA00000715 IRB00001223

Ref: W-CJ-160420-2 20/04/2016

***TO WHOM IT MAY CONCERN*:**

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: **Monica Tau (869717).**

Project title: **The association between hip dysfunction and lower quarter injuries in long distance: a systematic review.**

Reason: This study is a systematic review using information in the public domain. There are no human particpants.

UNIVERSITY OF THE WITWATERSRAND
PROF PE CLEATON-JONES
HREC (MEDICAL)
2016 -04- 20
JOHANNESBURG

Professor Peter Cleaton-Jones

Chair: Human Research Ethics Committee (Medical)

Copy – HREC (Medical) Secretariat: Zanele Ndlovu, Rhulani Mkansi.

Appendix VI: Plagiarism declaration

Faculty of Health Sciences, Postgraduate Office
Phillip V Tobias Building, 2nd Floor
Cnr York & Princess of Wales Terrace, Parktown 2193
Tel: (011) 717 2345 | Fax: (011) 717 2319
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PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Monica Tau (Student number: 869717) am a student registered for the degree of Msc Physiotherapy in the academic year 2018.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

Signature: _____ Date: 30/08/2018

Appendix VI: Turnitin reports

Turnitin Originality Report

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< 1% match (publications)
Jack Dix, Stephanie Marsh, Bart Dingenen, Peter Malliaras, "The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: A systematic review", Physical Therapy in Sport, 2018

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