STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH
253

Mari Leppänen

Prevention of Injuries among Youth Team Sports

The Role of Decreased Movement Control as a Risk Factor

JYVÄSKYLÄN YLIOPISTO

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2017

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ABSTRACT

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Good movement control is essential in team sports that require fast-paced running, pivoting, jumping and landing. Alterations in dynamic neuromuscular control may cause significant stress on the musculoskeletal system, and increase the risk of both acute and overuse injuries. The purpose of this dissertation was to investigate the effectiveness of interventions to prevent sports injuries, the incidence and severity of overuse injuries, and the role of decreased movement control as a risk factor for future injuries in young team sports athletes. The study methods included a systematic literature review and meta-analysis of randomized controlled trials, a retrospective epidemiological investigation on the prevalence of overuse injuries, a cross-sectional investigation on young athletes' movement control, and a prospective risk factor analysis on the biomechanical characteristics of a jump-landing task. The observational study population comprised a total of 401 young basketball and floorball players from the Tampere district. First, the study revealed that training interventions are effective to prevent sports injuries. Second, overuse injuries in youth basketball and floorball affected mainly the knee and the lower back, and caused long absences from training and competition. Third, decreased movement control was highly common, especially among young female players from basketball and floorball. Finally, stiff landings with less knee flexion and increased vertical ground reaction force were associated with increased risk of anterior cruciate ligament (ACL) injuries among young female team sports players. Certain deficiencies in young athletes' movement control and jump-landing technique might be related to future injuries. However, the current screening method based on a jump-landing task is not accurate enough to identify athletes who will suffer future injury. Neuromuscular training can improve movement control during sporting tasks and is effective in reducing the risk of injuries. The actions to prevent ACL injuries in young female team sports players should include a focus on avoiding stiff landing patterns by teaching the players to increase knee flexion during landing and cutting movements.

Keywords: sports injuries, team sports, adolescents, movement control, neuromuscular control, anterior cruciate ligament, injury prevention

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Tampere, December 1st 2016

Mari

FIGURES

TABLES

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, which are referred to in the text by their Roman numerals.

I Leppänen M, Aaltonen S, Parkkari J, Heinonen A, Kujala UM. Interventions to prevent sports related injuries: A systematic review and meta-analysis of randomised controlled trials. Sports Medicine 2014; 44: 473–486.

II Leppänen M, Pasanen K, Kujala UM & Parkkari J. Overuse injuries in youth basketball and floorball. Open Access Journal of Sports Medicine 2015; 6: 173–179.

III Leppänen M, Pasanen K, Kulmala J-P, Kujala UM, Krosshaug T, Kannus P, Perttunen J, Vasankari T, Parkkari J. Knee control and jump-landing technique in young basketball and floorball players. International Journal of Sports Medicine 2016; 37: 334–338.

IV Leppänen M, Pasanen K, Kujala UM, Vasankari T, Kannus P, Äyrämö S, Krosshaug T, Bahr R, Avela J, Perttunen J, Parkkari J. Stiff landings are associated with increased ACL injury risk in young female basketball and floorball players. American Journal of Sports Medicine 2016, published online September 16, doi: 10.1177/0363546516665810.

ABBREVIATIONS

ACL	anterior cruciate ligament
ASIS	anterior superior iliac spine
BMI	body mass index
CI	confidence interval
FAI	femoroacetabular impingement
GRF	ground reaction force
IC	initial contact
HR	hazard ratio
JK	jumper's knee
LESS	the Landing Error Scoring System
MKD	medial knee displacement
MBIM	model-based image-matching
mm	millimeter
MRI	magnetic resonance imaging
MTP	medial tibial pain
N	Newton
Nm	Newton meter
NKS	normalized knee separation
OR	odds ratio
PFP(S)	patellofemoral pain (syndrome)
PROFITS	Predictors of Lower Extremity Injuries in Team Sports (study)
RCT	randomized controlled trial
rCMJ	repeated counter movement jump
ROC	receiver operating characteristic
ROM	range of motion
RR	risk ratio
SD	standard deviation
SLDJ	single-leg drop jump
VDJ	vertical drop jump
vGRF	vertical ground reaction force
2D	two-dimensional
3D	three-dimensional

CONTENTS

APPENDICES
ORIGINAL PUBLICATIONS

1 INTRODUCTION

Sports participation in adolescence has multiple health benefits, but also carries a risk of injury (Maffulli & Bruns 2000, Mattila et al. 2009). Sports injuries can diminish the benefits of sports participation if a young athlete is unable to return to sport due to an injury or its side-effects (Maffulli et al. 2010). Injuries may also cause long-term disabilities, such as early osteoarthritis (Kujala et al. 1995). It has been shown that adolescent athletes who have sustained a severe knee injury are, after a few years, more prone to have functional deficits, decreased quality of life, and are at increased risk of obesity compared to uninjured athletes (Whittaker et al. 2015). Anterior cruciate ligament (ACL) injuries are one of the most debilitating and also one of the most common knee injuries (Hewett et al. 2016). In addition, overuse knee injuries, especially patellofemoral pain (PFP), are common in sports involving jumping, cutting and pivoting (Myer et al. 2010).

Basketball and floorball are popular team sports among young people in Europe, and have a high incidence of injuries (McCarthy et al. 2013, Messina, Farney & DeLee 1999, Pasanen et al. 2008a, Yang et al. 2012). Good movement control is essential in team sports that require fast-paced running, pivoting, jumping and landing. Alterations in dynamic neuromuscular control may cause significant stress on the joints and ligaments (Hewett et al. 2005b), and increase the risk of both acute (Dingenen et al. 2015, Hewett et al. 2005a) and overuse injuries (Boling et al. 2009, Myer et al. 2010, van der Does et al. 2016).

It is well established that the incidence of ACL injuries is high among female athletes in particular (Agel, Arendt & Bershadsky 2005, Messina, Farney & DeLee 1999, Tranaeus, Götesson & Werner 2016). Females also have a tendency for excessive knee valgus movement during sports tasks (Ford, Myer & Hewett 2003, Holden, Boreham & Delahunt 2015, Kernozek et al. 2005). Many investigations have suggested that factors such as knee valgus (Hewett et al. 2005a, Krosshaug et al. 2007, Olsen et al. 2004, Waldén et al. 2015) and stiff landings (Boden et al. 2000, Chappell et al. 2007, Myers et al. 2011, Sell et al. 2007, Sugimoto et al. 2015) play a role in loading the ACL, and therefore predispose athletes to a greater risk of ACL injury. However, there is a limited amount of high-quality prospective evidence on biomechanical risk factors related to ACL injury risk (Sharir et al. 2016).

Although neuromuscular training has been shown to reduce the risk of ACL injuries (Yoo et al. 2010b), the incidence of ACL injuries remains high, especially among female athletes (Agel, Arendt & Bershadsky 2005, Deitch et al. 2006, Tranaeus, Götesson & Werner 2016, Waldén et al. 2011). Furthermore, it has not been thoroughly established why training interventions are effective. In order to target prevention strategies to athletes at risk, injury mechanisms and risk factors need to be identified.

An increasing number of studies has investigated injury prevention methods, leading to a need to update the evidence on interventions to prevent sports injuries. The first aim of this dissertation is to clarify which interventions are effective in reducing the risk of sports injuries. Some of the biomechanical risk factors of ACL injuries might be similar to knee overuse injuries (Boling et al. 2009, Myer et al. 2010, Myer et al. 2015), and little is known about overuse injuries in youth team sports. Thus, the second aim of the thesis is to examine the incidence of overuse injuries among young team sports players. Finally, there is a lack of high-quality evidence on the biomechanical risk factors of ACL injuries, and therefore the main aim of the dissertation is to investigate young athletes' movement control and its relation to the risk of ACL injuries.

2 REVIEW OF THE LITERATURE

2.1 Theoretical model of injury prevention research

Injury prevention research is commonly described as a four-step sequence model (Figure 1) developed by van Mechelen, Hlobil and Kemper (1992). First, the magnitude of the injury problem in a certain population has to be identified and described in terms of injury incidence and severity. The second step is to establish risk factors and injury mechanisms that have an effect on the occurrence of sports injuries. Based on the information gathered in the second phase, the third step is to provide measures that have the potential to reduce the risk of injuries. Finally, the effectiveness of a preventive action should be assessed in randomized clinical trials and, after several intervention trials have been conducted, evaluated by means of a meta-analysis (van Mechelen, Hlobil & Kemper 1992).

In order to receive reliable and comparable information on sports injury research, many factors need to be considered. First, it is essential to use clearly defined methodologies (Brooks & Fuller 2006). The term *sports injury* has to be defined unambiguously and universally based on a present recommendation or a consort statement (van Mechelen, Hlobil & Kemper 1992).

Second, it is important that injury incidence reflects the true magnitude of the problem and is enunciated in a way that it allows injury rates for different sports and populations to be compared (van Mechelen, Hlobil & Kemper 1992). Epidemiological studies commonly report the absolute number of injuries or number of injured individuals, relative proportion of injuries or incidence of injuries. Injury incidence expressed as the number of injuries per 1,000 hours of sports participation includes the time an individual is actually at risk of being injured, and is the most precise number to reflect the phenomenon. Using injury incidence with exposure time requires that sports participation is clearly defined and also that differences in training and competition as well as in recreational and competitive sports are considered (van Mechelen, Hlobil & Kemper 1992).

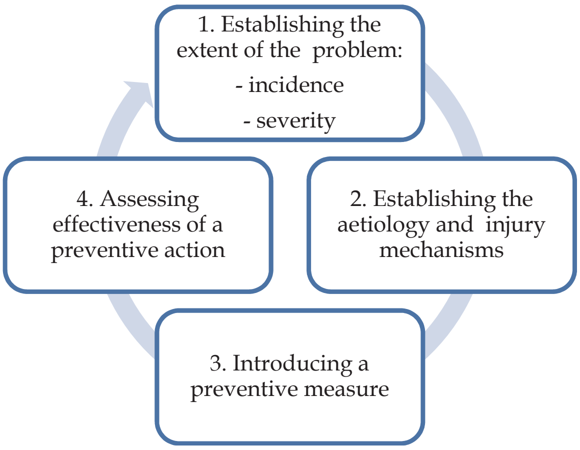

FIGURE 1 The sequence of injury prevention research, adopted from van Mechelen, Hlobil & Kemper (1992).

Finally, the results of sports injury research are affected by the chosen study design and the methodology as well as the representativeness of the sample (van Mechelen, Hlobil & Kemper 1992).

2.2 Sports injuries

The loads that act on the body during every sporting activity are a combination of external forces that act on the body from the outside and internal forces that act within the body. An injury takes place when the tissue is affected by such amount of loading that exceeds the tissue's ability to maintain its structure either acutely or chronically (McBain et al. 2012b). In general, all types of injuries that occur during sports related activity are being considered as sports injuries. For research purposes, however, the criteria for what counts as a sports injury need to be clearly and consistently defined (Brooks & Fuller 2006, Fuller et al. 2006). Currently, a number of consensus statements on injury definitions and data collection for studies of injuries in different sports have been published (Fuller et al. 2006, Fuller et al. 2007, McCrory et al. 2013, Mountjoy et al. 2016, Pluim et al. 2009, Timpka et al. 2014, Weir et al. 2015).

2.2.1 Acute injuries

Acute injury (or traumatic injury) is a physical complaint, which is caused by energy transfer that acutely exceeds the body's ability to maintain its structural and/or functional integrity (Fuller et al. 2007). Acute injury has a specific, identifiable event responsible for the injury (Fuller et al. 2006). Two widely used and acceptable injury definitions for acute injuries are based on medical attention and time-loss from sports participation (Brooks & Fuller 2006, Fuller et al. 2006). Injury is defined as a medical attention injury if it requires any treatment by a physician or other medical staff. Injury is referred to as a time-loss injury if the injury results in an athlete being unable to take full part in training or competition (Fuller et al. 2006).

Acute injuries occur mostly in high-speed sports, characterized by sudden changes of direction, rapid accelerations, decelerations, stops, and jump-landings. These sports include team sports where there are also a large number of physical contacts with other players (Darrow et al. 2009, Tranaeus, Götesson & Werner 2016, Yang et al. 2012).

Acute injuries can be further classified according to whether they occurred during training or competition or whether there was contact to another player or other object (Fuller et al. 2007). Contact injuries are defined as injuries that result from direct contact to the injured body part, such as a direct blow to the knee that causes an ACL rupture. Contact can also be indirect, such as a tackle at the shoulder which causes a loss of balance and results in a lower extremity injury. Non-contact injuries are injuries that occur without contact to any outside object. Non-contact and also indirect contact injuries often result from loss of adequate movement control.

2.2.2 ACL injuries

2.2.2.1 Anatomy and function of ACL

The anterior cruciate ligament (ACL) originates from the posteromedial surface of the lateral femoral condyle and runs inferiorly, medially and anteriorly towards its insertion on the anterior intercondylar area of the tibia. The ACL consists of two bundles, which differ structurally and functionally. An anteromedial bundle tightens at 90 degrees of knee flexion, whereas a posterolateral bundle is tight when the knee is fully extended (Duthon et al. 2006, Markatos et al. 2013).

The ACL functions as the main stabilizer against anterior translation of the tibia (Markatos et al. 2013, Petersen & Zantop 2007). The ACL produces 85% of the restraining force for anterior translation at 30 degrees of knee flexion (Butler, Noyes & Grood 1980). It also restricts internal rotations (particularly when the knee is extended), external rotations as well as varus-valgus angulation, especially under weightbearing movements (Duthon et al. 2006, Markatos et al. 2013, Petersen & Zantop 2007).

2.2.2.2 ACL injury occurrence

Most ACL injuries occur in non-contact situations during direction changes, cutting maneuvers or when landing from a jump (Alentorn-Geli et al. 2009, Boden et al. 2000, Cochrane et al. 2007, Krosshaug et al. 2007, Olsen et al. 2004, Stuelcken et al. 2015, Waldén et al. 2015). The incidence of ACL injuries is high in pivoting and jumping sports such as football, basketball and handball (Agel, Arendt & Bershadsky 2005, Myklebust et al. 1997, Tirabassi et al. 2016, Waldén et al. 2011). Furthermore, ACL injuries are 3 to 5 times more common among female athletes than among male ones (Agel, Arendt & Bershadsky 2005, Arendt & Dick 1995, Renstrom et al. 2008, Waldén et al. 2011). Most of the injuries occur during competition. For example, in male professional football players, ACL injury rate is as much as 20 times higher in matches compared with training (Waldén et al. 2016).

2.2.3 Overuse injuries

Overuse injuries are caused by a repetitive microtrauma and have no single, identifiable event causing the injury (Fuller et al. 2006). Overuse injuries are common in sports that include monotonous training sessions, such as endurance type of sports (Andersen et al. 2013, Clarsen, Krosshaug & Bahr 2010, Ristolainen et al. 2010) or repetitious movement patterns, such as technical sports (Jacobsson et al. 2013). In high-speed sports, (e.g. team sports) most of the injuries are acute injuries, and overuse injuries represent approximately 17–30% of all injuries (Deitch et al. 2006, Drakos et al. 2010, Pasanen et al. 2008a, Snellman et al. 2001, Starkey 2000, Wikström & Andersson 1997). High training volume and frequent competitions have been proposed to be factors associated with overuse injury risk in team sports (Lian, Engebretsen & Bahr 2005, Myklebust et al. 2011, Visnes & Bahr 2013).

Overuse injuries may have a long-term influence on performance and even daily activities (Kettunen et al. 2002). In growing athletes, overuse injuries are a special concern because repetitive overloading can lead to growth disturbances and deformities (Caine, DiFiori & Maffulli 2006). Although a great deal of studies regarding both epidemiology and prevention of acute injuries have been published (McBain et al. 2012a), a relatively small amount of research exists on the area of overuse injuries (Jacobsson et al. 2013), especially in young athletes.

2.2.4 Recurrent injuries

A recurrent injury can be defined as an injury of the same type and same site as an index injury occurring after a person has returned to full participation from the index injury (Fuller et al. 2006). Recurrence can be referred to as an ‘early’, ‘late’ or ‘delayed’ recurrence based on the time for recurrence to occur after the index injury, which is within 2 months, 12 months or more than 12 months, respectively (Fuller et al. 2006, Fuller et al. 2007).

2.2.5 Severity of sports injuries

The severity of sports injuries can be classified into four categories based on the number of days lost from full participation in training and competition. The categories are as follows: a minimal injury (an injury causing absence from full participation for 1–3 days), a mild injury (absence from full participation for 4–7 days), a moderate injury (absence from full participation for 8–28 days), and a severe injury (absence from full participation for 29 or more days). In addition, an injury that causes an athlete to retire from sports as a direct consequence of the injury is a career-ending injury (Fuller et al. 2006).

2.3 Injury prevention

During the last ten to fifteen years, interest in sports injury research has increased and a high number of studies on injury prevention have been published (Klugl et al. 2010). Ekstrand et al. (1983) were the first to investigate the efficacy of a preventive measure in sports using a randomized controlled study design. Since their work, numerous interventions in various sports have been studied.

Injury prevention interventions studied in randomized controlled trials (RCTs) can be classified into three categories: equipment, training and regulatory interventions (Klugl et al. 2010). Equipment interventions, such as stabilizing orthoses, braces and taping, attenuating insoles, and head protectors, were of special interest in the earliest studies (Aaltonen et al. 2007). Nowadays, an increasing amount of training interventions including different components of motor skills training (e.g. balance, coordination, agility) and physical fitness (e.g. strength, flexibility) have been studied in RCTs (McBain et al. 2012a). Regulatory intervention studies, however, are scarce (Klugl et al. 2010).

The results from different trials investigating the same intervention sometimes differ from one another. Based on a single study, the effectiveness of an intervention cannot be generalized to all sports populations. In order to summarize the findings from multiple studies, several systematic reviews have been published. In 2007, Aaltonen et al. conducted a large systematic review summarizing the effects of all randomized controlled interventions targeted at preventing sports injuries. Since their work, which was presumably the first review to include all randomized controlled trials available, many new injury prevention trials have been published. A large number of studies on a particular intervention allow statistical pooling of the data as well as a meta-analysis to provide evidence for the efficacy of the interventions (McKeon, Medina & Hertel 2006).

2.3.1 Training interventions aimed to prevent injuries

Previous systematic reviews (Herman et al. 2012, Hubscher et al. 2010, Stojanovic & Ostojic 2012) and a meta-analysis (Yoo et al. 2010b) have emphasized the role of neuromuscular training to reduce the risk of ACL injuries in female athletes (Stojanovic & Ostojic 2012, Yoo et al. 2010b), knee and ankle injuries in pivoting sports (Hubscher et al. 2010), and lower extremity injuries in various sports populations (Herman et al. 2012). Another possibly effective method found in a previous systematic review includes eccentric strength training for prevention of hamstring strains (Hibbert et al. 2008). However, it should be acknowledged that the previously mentioned studies were published a few years ago. Since then, an increasing amount of trials have been published.

2.3.2 Other interventions

Most of the previous systematic reviews on equipment interventions have regarded external joint supports and foot orthoses. These studies have stated that ankle supports are effective in reducing ankle injuries (Dizon & Reyes 2010). The evidence on the effectiveness of knee braces is inconsistent (Pietrosimone et al. 2008). According to one meta-analysis (Collins et al. 2007) and a systematic review (Hume et al. 2008), foot orthoses seem to be effective in preventing lower-limb overuse injuries.

2.4 Injury risk factors

Factors that are associated with the risk or likelihood that an athlete will get injured during a sporting activity are called risk factors (Hopkins et al. 2007). Risk factors for sports injuries are often classified into two groups: intrinsic risk factors that are related to subject characteristics and extrinsic risk factors that are other than subject related factors (Meeuwisse 1994) (Table 1).

TABLE 1 Intrinsic and extrinsic risk factors for sports injuries. Adapted from (Parkkari, Kujala & Kannus 2001, Bahr & Krosshaug 2005).

Intrinsic risk factors
Age (maturation, aging)
Gender
Body composition (e.g. body weight, height, BMI, anthropometry)
Health (e.g. previous injuries, joint instability)
Physical fitness (e.g. muscle strength, aerobic fitness, joint ROM)
Anatomy (e.g. alignment)
Skills (e.g. sport specific technique, motor abilities)
Psychological factors (e.g. motivation, risk taking, stress coping, competitiveness)
Extrinsic risk factors
Sports factors (e.g. coaching, rules, level of competition, position in the team, training frequency and intensity)
Environment (e.g. weather, time of season, playing surface, maintenance)
Protective equipment (e.g. helmet, shin guards)
Sports equipment (e.g. footwear, racket, stick)

BMI= body mass index; ROM= range of motion.

2.4.1 Intrinsic risk factors

Intrinsic risk factors include factors that are internal to the athlete (Meeuwisse 1994). Some of the intrinsic risk factors are non-modifiable (e.g. age or gender) and some are modifiable (e.g. neuromuscular control or strength).

The influence of gender on injury risk seems to vary according to the type of sport and injury. Investigations from the summer Olympic Games in 2008 and 2012 showed similar overall injury rates between men and women (Engebretsen et al. 2013, Junge et al. 2009). Higher acute injury rates are usually reported among men (Parkkari et al. 2004, Yang et al. 2012), whereas overuse injuries seem to be more common among female athletes (Roos et al. 2015, Wright et al. 2015, Yang et al. 2012). However, studies focusing on a particular sport or injury type have found different occurrences. According to a recent investigation, elite male floorball players have a higher proportion of overuse conditions, especially back problems, compared with female players (Tranaeus, Götesson & Werner 2016). In addition, patellar tendinopathy (jumper's knee) is nearly twice as common among males as it is among females (Zwerver, Bredeweg & van den Akker-Scheek 2011). Furthermore, several studies have found that female athletes, especially in sports including pivoting and cutting, have a higher incidence of severe knee injuries compared with males participating in the same sports (Agel, Arendt & Bershadsky 2005, Darrow et al. 2009, Messina, Farney & DeLee 1999, Tirabassi et al. 2016, Tranaeus, Götesson & Werner 2016).

Injury risk is usually low in childhood sports (Emery 2003), but increases with age (Freckleton & Pizzari 2013, Froholdt, Olsen & Bahr 2009, Jayanthi et al. 2015, Rossler et al. 2016, Taimela, Kujala & Osterman 1990). Many studies have shown that the risk of ACL injury increases in girls during their adolescence (Hägglund & Waldén 2015, Shea et al. 2004, Waldén et al. 2011). Similarly, Roos et al. (2015) reported 3.28 times higher overuse injury rates in college sports than in high school sports.

Previous injury is one of the most known and also one of the strongest intrinsic risk factor across different sports and injury types (Bourne et al. 2015, Freckleton & Pizzari 2013, Giroto et al. 2015, Hägglund & Waldén 2015, Krosshaug et al. 2016, Wright et al. 2015). Interestingly, a previous injury to a different body part might also increase the risk of certain injuries. Zazulak et al. (2007) reported that a history of low back pain was associated with knee ligament injuries, and Freckleton and Pizzari (2013) pointed out that previous knee and calf injuries may be associated with future hamstring strain.

Anthropometrics and anatomical factors have been suggested to influence the injury risk. Increased body mass index (BMI) is a commonly reported risk factor (Fousekis, Tsepis & Vagenas 2012, Gribble et al. 2016, Nilstad et al. 2014b). Generalized joint laxity, particularly knee joint laxity (genu recurvatum), have been proposed as being associated with a higher risk of lower extremity injuries, especially ACL injuries (Alentorn-Geli et al. 2009) and overuse knee injuries (Devan et al. 2004). Another anatomical factor associated with both anterior knee pain and patellar dislocation is a condition called patella alta (Kujala et al. 1986), which is a malalignment of the patella causing instability of the knee joint. In addition, certain asymmetries, such as leg length discrepancy (Fousekis et al. 2011), seem to increase the risk of injuries.

Important factors are one's level of physical fitness, including aerobic fitness and muscle strength (Taanila et al. 2011, Taanila et al. 2012, Taimela, Kujala & Osterman 1990), as well as motor fitness, including balance, agility, and coordination (Gribble et al. 2016, Plisky et al. 2006). Neuromuscular fatigue increases the risk of ligament injuries due to the decreased ability of muscles to stabilize the joint (Alentorn-Geli et al. 2009, De Ste Croix et al. 2015). An imbalance in muscle strength seems to be particularly unfavourable. Between-limb imbalance in eccentric knee flexor strength has been shown to increase the risk of hamstring strains (Bourne et al. 2015, Fousekis et al. 2011), and a low hamstrings-to-quadriceps strength ratio has been detected as a risk factor for overuse knee injuries (Devan et al. 2004). Furthermore, weakness of the vastus medialis part of the quadriceps femoris muscle, in particular, may cause instability of the patella, which is related to chondromalacia of the patella (Väätäinen et al. 1995).

2.4.2 Extrinsic risk factors

Extrinsic factors are factors that have an impact on the athlete but which are primarily related to ongoing activity (Taimela, Kujala & Osterman 1990). These factors facilitate the manifestation of the injury (Meeuwisse 1994). Typical extrinsic factors are environment, weather conditions, equipment, playing surface, training-related factors, and contacts with other persons or objects.

Extrinsic factors can be divided into factors related to sports, environment and equipment. The type of sport (e.g. endurance sports, contact sports and team sports), position in a team, level of competition and training-related factors are sports factors. Training factors include frequency, intensity and content of training (Parkkari, Kujala & Kannus 2001), of which training errors, such as initiating training too suddenly or returning to sports too soon after an injury, play a particularly significant role in the outcome of an injury (Taimela, Kujala & Osterman 1990). Environmental factors include the type of playing surface, weather conditions, time of season, indoor/outdoor conditions as well as human factors (coaching, rules, referees, teammates and opponents) (Bahr & Krosshaug 2005, Parkkari, Kujala & Kannus 2001). Equipment factors include protective equipment (e.g. helmet, shin guards) and sporting equipment (e.g. footwear, clothing, skis, racket).

In adolescence and early adulthood, sports-specialized intensive training (Jayanthi et al. 2015) and participation in sports clubs (Mattila et al. 2009) have been reported as extrinsic factors related to injuries. High training volume and intensity as well as competition exposure increase the risk of overuse injuries in particular (DiFiori et al. 2014, Visnes & Bahr 2013).

Of the environmental factors, the effects of playing surfaces on injury risk have been studied in many team sports, such as football (Hägglund & Waldén

2015), floorball (Pasanen et al. 2008c), rugby (Williams et al. 2015), and American football (Williams, Hume & Kara 2011), but the evidence is still inconclusive (Dragoo & Braun 2010).

2.4.3 Causation in sports injuries

There is a strong agreement that many things play a role before an injury occurs (Bahr & Krosshaug 2005, Meeuwisse et al. 2007). Causation in sports injury has been described as a multifactorial model, first introduced by Meeuwisse (1994) and later elaborated by Bahr and Krosshaug (2005) and further modified by Meeuwisse et al. (2007) (Figure 2). According to this model, intrinsic risk factors predispose athlete to injuries. Each athlete is affected by a combination of their own intrinsic risk factors (Meeuwisse et al. 2007). This means that two athletes, even when exposed to the same extrinsic factors, have a different susceptibility, and explains why some athletes seem to be more prone to injuries than others.

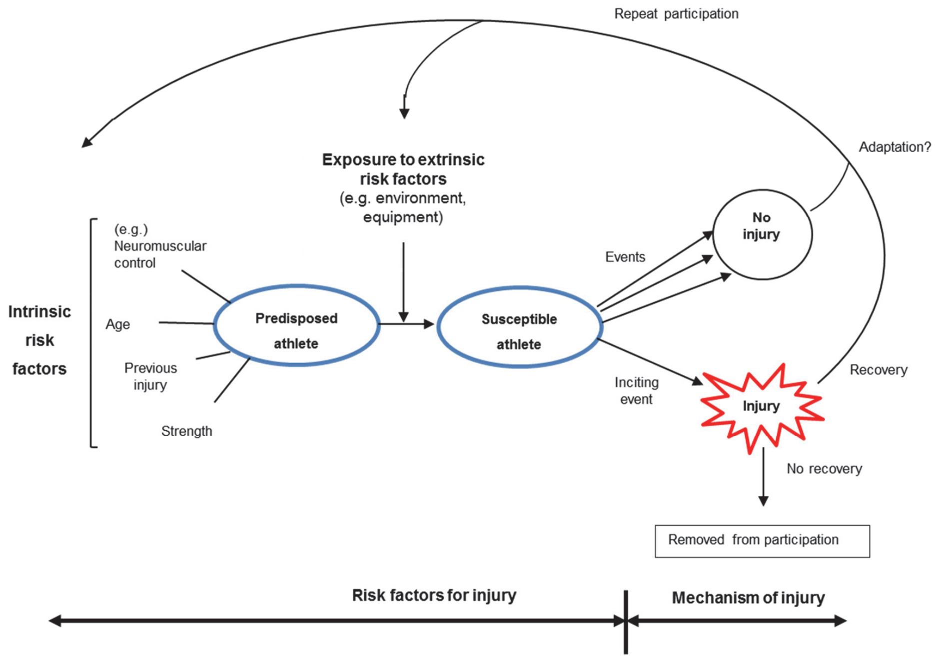

FIGURE 2 A dynamic model of etiology of sports injury, adapted from Meeuwisse et al. (2007).

While intrinsic risk factors predispose athletes to injury, exposure to extrinsic risk factors makes the athlete susceptible to injury. Intrinsic and extrinsic risk factors often interact, which may increase the risk of being injured (Meeuwisse et al. 2007). However, the presence of both intrinsic and extrinsic factors and interactions of all risks is usually not enough for injury to occur. The final link between a susceptible athlete and the injury is an inciting event, which is often more visually related to injury (Meeuwisse 1994).

A predisposing factor can be diminished through adaptation to the environment or to potentially injurious situations in which an athlete avoids injury. In addition, an injury and recovery from it may alter an athlete's internal features. Thus, after returning to sports, the athlete is predisposed to different combinations of intrinsic risk factors. Similarly, susceptibility to injury can change if the injury results in an athlete changing their equipment or other extrinsic risk factors (Meeuwisse et al. 2007). Injury risk factors and predictors, although commonly used interchangeably, are not synonyms. Predictive factors have a strong association with injury risk and also predict injury with sufficient accuracy (Bahr 2016).

2.5 Injury mechanism

As explained earlier, an injury is the result of a complex interaction of intrinsic and extrinsic risk factors and all the events leading to the injury situation (Bahr & Krosshaug 2005). Thus, in order to develop effective prevention programs, there needs to be a thorough understanding of injury mechanisms (Bahr & Krosshaug 2005, Meeuwisse 1994, van Mechelen, Hlobil & Kemper 1992). In recent years, there has been an increasing amount of literature on sports injury mechanisms, especially regarding knee injuries, possibly due to their frequency and severity.

2.5.1 Biomechanics of ACL injury

Over the past decade, the mechanism of ACL injuries has been studied in several investigations. Injury situations in various team sports such as basketball (Boden et al. 2000, Boden et al. 2009, Ebstrup & Bojsen-Møller 2000, Koga et al. 2010), handball (Boden et al. 2009, Koga et al. 2010, Krosshaug et al. 2007, Olsen et al. 2004), football (Boden et al. 2000, Brophy et al. 2015, Koga et al. 2011, Waldén et al. 2015), netball (Stuelcken et al. 2015), and Australian rules football (Cochrane et al. 2007) have been studied using video analyses from real injury situations. Most of these injury mechanism studies are based on a simple visual inspection to determine injury characteristics and joint positions (Boden et al. 2000, Brophy et al. 2015, Krosshaug et al. 2007, Olsen et al. 2004, Stuelcken et al. 2015, Waldén et al. 2015). Only few studies have used more accurate methods such as computer-based analysis (Boden et al. 2009) and model-based image matching (Koga et al. 2010, Koga et al. 2011).

According to the investigations presented in Table 2, athletic actions during which ACL injuries typically take place include decelerations (with and without changing direction), jump-landings and cutting maneuvers. Most of the injuries occur in single-leg activities such as landing on one leg or side-step cutting (Krosshaug et al. 2007, Olsen et al. 2004, Waldén et al. 2015). Even in two-legged landings, the body weight is typically unevenly distributed in a way that almost all of the weight is on the injured leg (Waldén et al. 2015). It has been suggested that distribution of injuries between legs is different among male and females (Brophy et al. 2010, Brophy et al. 2015). Most of the non-contact ACL injuries among female footballers involve the non-dominant (i.e. supporting) leg, whereas male footballers tend to injure their dominant (i.e. kicking) leg more often (Brophy et al. 2010). The injury occurs approximately 30 to 40 milliseconds after initial foot contact with the ground (Koga et al. 2010, Koga et al. 2011, Krosshaug et al. 2007).

The following three biomechanical characteristics seem to be present in most of the injury cases: 1. knee valgus alignment, 2. internal and/or external rotation of the tibia in relation to femur, and 3. small knee flexion angle. Thus, the mechanism for an ACL injury is thought to include knee motions in all three planes (frontal plane valgus, transverse plane rotation, and sagittal plane flexion). However, it has not been thoroughly established in which order these three motions exist, whether they are all present, which of the suggested motions is the most critical cause of the injury and whether these movements occur before or after the ligament rupture (Koga et al. 2010, Koga et al. 2011, Krosshaug et al. 2007, Olsen et al. 2004, Waldén et al. 2015). Nevertheless, there is wide agreement that ACL injuries are multifactorial injuries, and many possible injury mechanisms exist.

TABLE 2 Summary of studies on ACL injury mechanism.

Study	Sport	Gender	No. of analyses	Injury situation	Valgus alignment	Valgus collapse	Int./ext. rotation*	Knee flexion
Boden et al. (2000)	Team sports	♂/♀	23	A (n=10) B (n=5)	Frequent	Frequent	Minimal	Low in all non-contact cases
Boden et al. (2009)	Team sports, cheerleading, gymnastics	♂/♀	29	A (n=18) B (n=11)	Frequent	Frequent	NA	Mean < 20°
Brophy et al. (2015)	Football	♂/♀	55	D (n=28) C (n=8)	Frequent in non-contact cases (n=14)	NA	NA	< 30° (71 % of cases)
Koga et al. (2010)	Handball Basketball	♀	10	C (n=7) B (n=3)	Frequent	Frequent	Ext. and int.	IC: mean 23°
Koga et al. (2011)	Football	♂	1	C (n=1)	Present	NA	Int. and ext.	26° – 35°
Krosshaug et al. (2007)	Basketball	♂/♀	30	B (n=23) C (n=4)	Frequent	Present in 11 cases (♀ 9, ♂ 2)	NA	IC: mean 15° (♀) and 9° (♂)
Olsen et al. (2004)	Handball	♀	20	C (n=12) B (n=4) A (n=2)	Present in all cases	Frequent	Ext. or int.	< 20° in almost all cases
Stuelcken et al. (2015)	Netball	♀	16	B (n=13) C (n=1)	Frequent	Frequent	NA	Close to full extension (n=2)
Waldén et al. (2015)	Football	♂	21	C (n=11) B (n=5) E (n=12)	Frequent (n=11)	Infrequent (n=3)	NA	IC <20° in all cases

♂ = male; ♀ = female; Injury situations: A = changing direction/deceleration; B = landing from a jump; C = cutting; D = tackling; E = other; NA = not applicable; * Internal/external rotation of the tibia in relation to the femur.

2.5.2 Knee valgus loading

Some discrepancy exists in the literature regarding the use of terms when discussing knee valgus loading. *Valgus alignment* refers to the outward angulation of the distal segment of a bone or joint. At the knee joint, *valgus* may occur from two planes of motions: from a frontal plane motion of the distal tibia relative to the femur or from a transverse plane knee motion (femoral/tibial internal and external rotations) (Quatman & Hewett 2009). *Valgus collapse* (also *dynamic valgus*) refers to a substantial medial movement of the knee, which could result from knee valgus, internal rotation of the hip and external rotation of the tibia in relation to the femur (Hewett et al. 2005a, Waldén et al. 2015).

Many studies have found that knee valgus motion in athletic movements is more common among female athletes than male athletes (Ford, Myer & Hewett 2003, Holden, Boreham & Delahunt 2015, Kernozek et al. 2005). In addition, Krosshaug et al. (2007) reported that during injury situations valgus collapse occurred five times more often among female than male basketball players. Thus, it has been suggested that valgus collapse is a sex-specific knee motion occurring mainly among females (Quatman & Hewett 2009). In contrast to distinct valgus collapse, knee valgus alignment is frequently seen also in men's injury situations (Waldén et al. 2015).

Studies using video-analyses have reported both internal and external knee rotations during ACL injuries (Koga et al. 2010, Koga et al. 2011, Krosshaug et al. 2007, Olsen et al. 2004). It has been demonstrated that an increase in internal knee rotation (together with knee valgus) occurs within 30–40 milliseconds after initial foot contact with the ground and internal knee rotation is followed by external knee rotation (Koga et al. 2010, Koga et al. 2011). Furthermore, laboratory studies support the role of the internal tibial rotation as a contributing factor to ACL injuries (Kim et al. 2015, Meyer & Haut 2008), while external tibial rotation might not increase ACL loading (Fleming et al. 2001, Markolf et al. 1995).

2.5.3 Sagittal plane loading

Numerous studies have suggested that sagittal factors (e.g. high ground reaction force (GRF), great quadriceps muscle contraction force, and small knee flexion angle) contribute to ACL injuries (Boden et al. 2000, DeMorat et al. 2004, Kim et al. 2015, Koga et al. 2010, Koga et al. 2011, Meyer & Haut 2008, Olsen et al. 2004, Waldén et al. 2015). Activities such as landing from a jump or cutting maneuvers require a large ground reaction force to slow the movement. A posterior ground reaction force creates an external flexion moment at the knee. To avoid excessive knee flexion, internal knee extension moment is needed, and it is being produced by increased eccentric quadriceps contraction (Yu & Garrett 2007). The forceful contraction of the quadriceps creates an anterior shear force at the proximal end of the tibia through the patella tendon (Yu & Garrett 2007). Various laboratory studies have shown that the anterior tibial shear force is a major loading mechanism of the ACL (Berns, Hull & Patterson 1992, Fleming et al. 2001, Markolf et al. 1995, Yu & Garrett 2007), and the shear force produced by aggressive quadriceps contraction can even cause a rupture of the ACL (DeMorat et al. 2004).

Landing techniques are commonly described by using the terms *stiff* and *soft* according to the attained peak knee flexion angle during the landing phase (DeVita & Skelly 1992, Myers et al. 2011). A stiff landing can be defined as a landing technique that includes a small knee flexion angle compared with a soft landing, which is characterized by more flexed knees. The small knee flexion angle in a stiff landing is likely accompanied by erect body posture and a small range of motion (ROM) in hip and ankle joints also (DeVita & Skelly 1992). Stiff landings are associated with higher GRFs (DeVita & Skelly 1992, Laughlin et al. 2011, Myers et al. 2011) and knee extension moments (Myers et al. 2011) compared with a softer landing technique. Furthermore, a decrease in knee flexion angle increases patella tendon-tibia shaft angle and ACL elevation angle (Yu & Garrett 2007), which increases the anterior tibial shear force and the ligament strain (Figure 3). ACL loading under various loading states has been shown to increase as the knee flexion angle decreases (Beynnon et al. 1995, Markolf et al. 1990, Markolf et al. 1995).

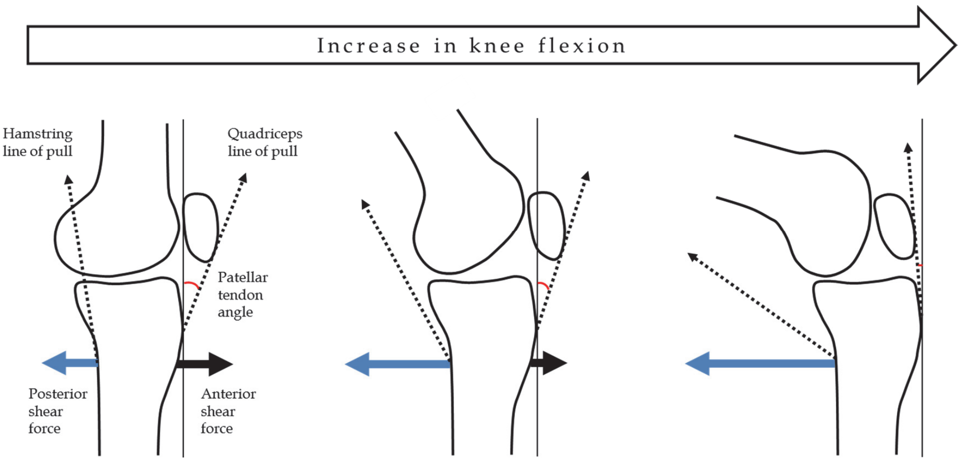

FIGURE 3 Increase in knee flexion decreases the patellar tendon angle (red arc) and the anterior tibial shear force (black arrow). Anterior shear force increases the tension on the ACL, whereas posterior shear force (blue arrow, produced by the hamstrings) protects the ACL. Modified from Kernozek et al. (2013) and Pandit et al. (2005).

Some previous studies have reported sagittal plane loading factors such as decreased knee flexion angles (Holden et al. 2015, Malinzak et al. 2001, Yu et al. 2005), higher anterior shear forces (Chappell et al. 2002), greater knee extension moments (Chappell et al. 2002), and greater GRFs (Kernozek et al. 2005) as being more common among female athletes compared with males in various athletic tasks. However, a recent meta-analysis observed no gender differences in knee flexion or landing forces (Holden, Boreham & Delahunt 2015), and it has been proposed that gender differences occur mainly in frontal plane biomechanics and not sagittal plane (Kernozek et al. 2005).

2.6 Neuromuscular control

The sudden accelerations, decelerations, directional changes and repeated jumps common in team sports such as basketball and floorball impose high loads at the lower extremities. Muscles work against these loads to produce and control the movement. The loads acting on limb muscles during fast-paced and frequently changing maneuvers are unpredictable. Thus, controlling the movement requires continuous feedback between the sensory and the motor pathways (Stein, Zehr & Bobet 2000).

The formation of dynamic neuromuscular response is shown in Figure 4. Mechanoreceptors (together with the visual system and vestibular system) accept information from the environment and transfer the message to the central nervous system (CNS), where it is processed at one of three levels: spinal level, lower brain level or cerebral level. Reaction at the spinal level produces immediate reflex responses, which stabilize and protect the joints, and also help mediate movements from the higher levels of the CNS. The lower brain area (basal ganglia, brain stem and cerebellum) controls complex movement patterns and is involved in timing and learning planned movements. The cerebral level is the highest level (produces the slowest motor response), and it controls voluntary movement. Proprioceptive control involves the two lowest levels (Hewett, Paterno & Myer 2002).

Dynamic neuromuscular imbalances related to knee injury risk can be divided into four categories: ligament dominance, quadriceps dominance, leg dominance and trunk dominance. *Ligament dominance* refers to a condition where the ground reaction force is absorbed by the ligaments instead of the muscles. *Quadriceps dominance* can be described as a tendency to use quadriceps muscles to stabilize the knee joint. *Leg dominance* refers to a side-to-side asymmetry in muscle strength or activation. *Trunk dominance* can be defined as an inability to control the trunk during athletic tasks (Hewett et al. 2010).

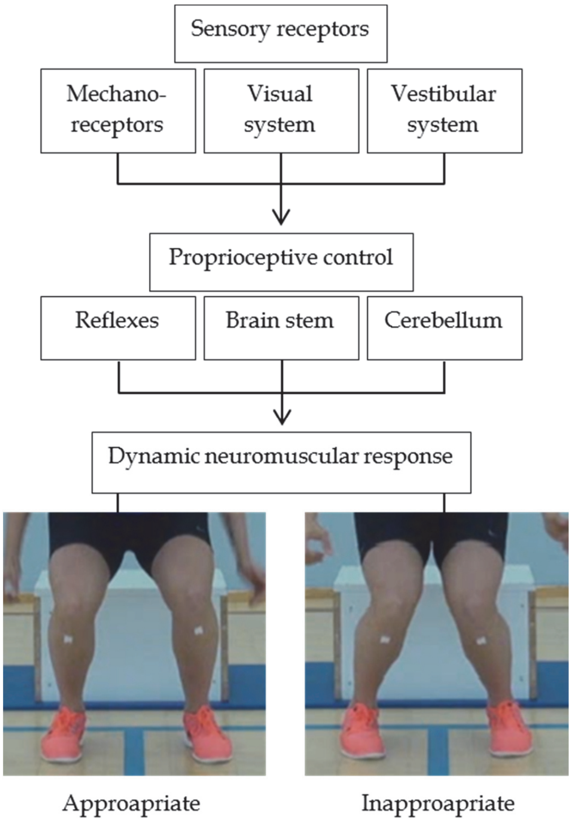

FIGURE 4 A flowchart of proprioceptive control and neuromuscular response, adapted from Hewett et al. (2002).

2.6.1 Neuromuscular control and injury risk

To date, prospective biomechanical risk factor analyses on neuromuscular control during functional tasks are scarce. Most of the prospective studies have aimed attention at double-leg jump-landing tasks (Boling et al. 2009, Hewett et al. 2005a, Krosshaug et al. 2016, Myer et al. 2010, Nilstad et al. 2014b, O'Kane et al. 2016, Padua et al. 2015, Smith et al. 2012, van der Worp et al. 2016), whereas three studies focused on a single-leg drop jump (SLDJ) (Dingenen et al. 2015, van der Does et al. 2016, Verrelst et al. 2014), one study on core stability (Zazulak et al. 2007) and one study on running biomechanics (Noehren, Hamill & Davis 2013). Risk factors for both acute and overuse knee injuries have been studied. Table 3 summarizes the findings from prospective studies investigating neuromuscular movement control.

TABLE 3 Summary of prospective studies investigating movement control and the risk of injury.

Study	Participants (injuries)	Injury	Screening test	Biomechanics		
				Frontal	Sagittal	Transverse
Boling et al. (2009)	1279 (40)	PFPS	VDJ (3D)		↓ Knee flexion angle ↓ vGRF	↑ Internal hip rotation angle
Myer et al. (2010)	131 (14)	PFPS	VDJ (3D)	↑ Knee abduction moment		
Noehren et al. (2013)	400 (15)	PFPS	Running analysis (3D)	↑ Hip adduction		
van der Worp et al. (2012)	49 (3)	JK	VDJ (3D)		↑Leg stiffness	
van der Does et al. (2016)	75 (24)	Knee (overuse)	SLDJ rCMJ (3D)		↓ Knee flexion moment ↑ vGRF	
Verrelst et al. (2014)	69 (21)	MTP	SLDJ (3D)			↑ Hip transverse plane motion
Hewett et al. (2005a)	205 (9)	ACL	VDJ (3D)	↑ Knee valgus angle ↑ Knee abduction moment		
Zazulak et al. (2007)	277 (25)	Knee (acute), ACL	Core stability	↑ Trunk displacement		
Smith et al. (2012)	44 (28)	ACL	VDJ (2D)	NA (LESS score)	NA (LESS score)	
Nilstad et al. (2014b)	173 (53)	Knee (acute)	VDJ (3D)	NA		
Dingenen et al. (2015)	37 (7)	Knee (acute)	SLDJ (2D)	↑ Knee valgus with lateral trunk motion		
O'Kane et al. (2016)	351 (43)	Knee (acute)	VDJ (2D)	↓ NKS		
Padua et al. (2015)	829 (7)	ACL	VDJ (3D)	↑ LESS score	↑ LESS score	
Krosshaug et al. (2016)	782 (42)	ACL	VDJ (3D)	↑ MKD		

ACL = anterior cruciate ligament; PFPS = patellofemoral pain syndrome; JK = jumper's knee; MTP = medial tibial pain; VDJ = vertical drop jump; SLDJ = single-leg drop jump; rCMJ = repeated counter-movement jump; 3D = three-dimensional motion analysis; 2D = regular video-analysis; MKD = medial knee displacement; NKS = normalized knee separation; LESS = the Landing Error Scoring System; vGRF = vertical ground reaction force; ↓ indicates decreased, ↑ indicates increased, NA indicates no significant associations found.

2.6.2 Vertical drop jump -test and ACL injury risk

Jump-landings are common maneuvers in many sports. A vertical drop jump (VDJ) test simulates rebounding movements in basketball, and is designed to monitor neuromuscular control of the knee (Ford, Myer & Hewett 2003). The VDJ test is performed by dropping down from an approximately 30-cm box, landing on two feet and immediately after landing jumping as high as possible (Nilstad et al. 2014b).

Hewett et al. (2005a) were the first to assess whether the jump-landing test can be used as a screening tool for identifying athletes at increased risk. The study utilized marker-based three-dimensional (3D) motion analysis and found that dynamic knee valgus (including high knee valgus angle and abduction moment) increased the risk of ACL injury in 205 young female athletes in mixed team sports. A decade later, Krosshaug et al. (2016) performed a corresponding investigation, in which they analyzed VDJ kinetics and kinematics in 710 female elite handball and soccer players, and found that only medial knee displacement was associated with increased risk of ACL injury. Furthermore, the authors concluded that the test is not a valid screening tool to predict injury in an elite female population.

In contrast to the complex 3D method, Smith et al. (2012) assessed the jump-landings using ordinary video cameras (frontal plane and sagittal plane). This investigation used the Landing Error Scoring System (LESS) to analyze kinematical characteristics of jump-landings in a large cohort, and it found no relationship between the LESS score (multiple frontal and sagittal plane factors included) and future ACL injury. A few years later, Padua et al. (2015) found injured athletes demonstrating higher LESS scores than uninjured participants. In both of these studies, the assessment of individual variables, such as frontal plane knee motion or knee flexion angle was limited, making it impossible to draw conclusions on different loading variables and ACL injury risk.

We can conclude, based on the findings from previous risk factor studies, that the evidence on biomechanical risk factors of ACL injuries is inconclusive and partly conflicting (Sharir et al. 2016). Furthermore, it is not certain if the VDJ test, despite its popularity in the field, is an appropriate test for predicting athletes with increased risk of ACL injury.

3 PURPOSE OF THE STUDY

The purpose of this dissertation was to investigate the effectiveness of interventions to prevent sports injuries, the incidence and severity of injuries, and the risk factors for future injuries in young team sports athletes. The specific study aims were to answer following research questions:

1. Which interventions are effective in reducing sports-related injuries? (*Study I*)

2. How common are overuse injuries in young basketball and floorball players? (*Study II*)

3. How common is decreased movement control among young basketball and floorball players? Is there a sex- or sports-related difference in knee control and jump-landing technique among young basketball and floorball players? (*Study III*)

4. What are the biomechanical risk factors for ACL injuries among young female basketball and floorball players? (*Study IV*)

4 RESEARCH METHODS

4.1 Research process and dissertation structure

This dissertation contains two parts and is based on four independent research articles published in peer-reviewed journals. The first part of the dissertation is a systematic review and meta-analysis of the current evidence on sports injury prevention. The second part of the dissertation contains three original articles based on the data from a three-year prospective injury risk factor study (Figure 5).

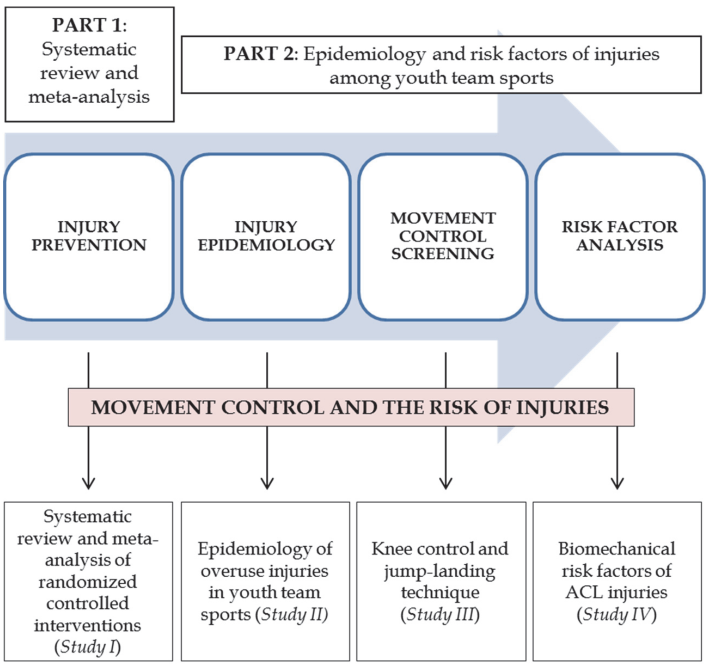

FIGURE 5 The dissertation structure.

Study I is a systematic review and meta-analysis summarizing the current evidence to determine if it is possible to prevent sports-related injuries. Study II is an epidemiological study that aims to investigate the prevalence of overuse injuries. Study III examines young athletes' movement control during a jump-landing task. Study IV is a risk factor analysis that aims to investigate the association between movement control deficiencies and the risk of future ACL injuries.

4.2 Part 1: Systematic review and meta-analysis

4.2.1 Systematic literature search

The literature search for the meta-analysis part of the dissertation was conducted in September 2013. The search was carried out by combining two independent, similarly conducted search processes. The first search was conducted by Aaltonen et al. (2007) until December 31, 2005, and it is described in their article. The second literature search was accomplished using the same search strategy as Aaltonen et al., except that it included studies published from January 1, 2006 to September 24, 2013.

Relevant trials were searched for in the following databases: PubMed, MEDLINE (Ovid), SPORTDiscus, the Cochrane Central Register of Controlled Trials, CINAHL (Cumulative Index to Nursing and Allied Health Literature), PEDro (the Physiotherapy Evidence Database), and Web of Science. The following key words and various combinations of the terms were used in the search: sports injury/ies, athletic injury/ies, prevention, preventive, randomiz/s/ed, controlled trial, and randomiz/s/ed controlled trial. In addition, the reference lists of articles retrieved and relevant reviews were searched manually.

4.2.2 Trial selection and data extraction

The electronic search process yielded in total 5,580 articles (4,803 items in the first search and 777 in the second). The retrieved articles were first assessed on the basis of titles and abstracts. After the first screening, 5,462 articles (4,755 and 707) were excluded. The remaining 118 potentially eligible articles (48 and 70) were evaluated more thoroughly on the basis of the full article. Relevant reviews and reference lists of retrieved articles were manually searched, and two studies were included as a result of the search.

Altogether 68 trials (32 and 36) were included in the present systematic review. Eight trials could not be pooled for meta-analysis due to a lack of sufficient data. Thus, 60 trials provided adequate data and were included in the meta-analysis. The literature search is presented as a flow chart in Figure 6.

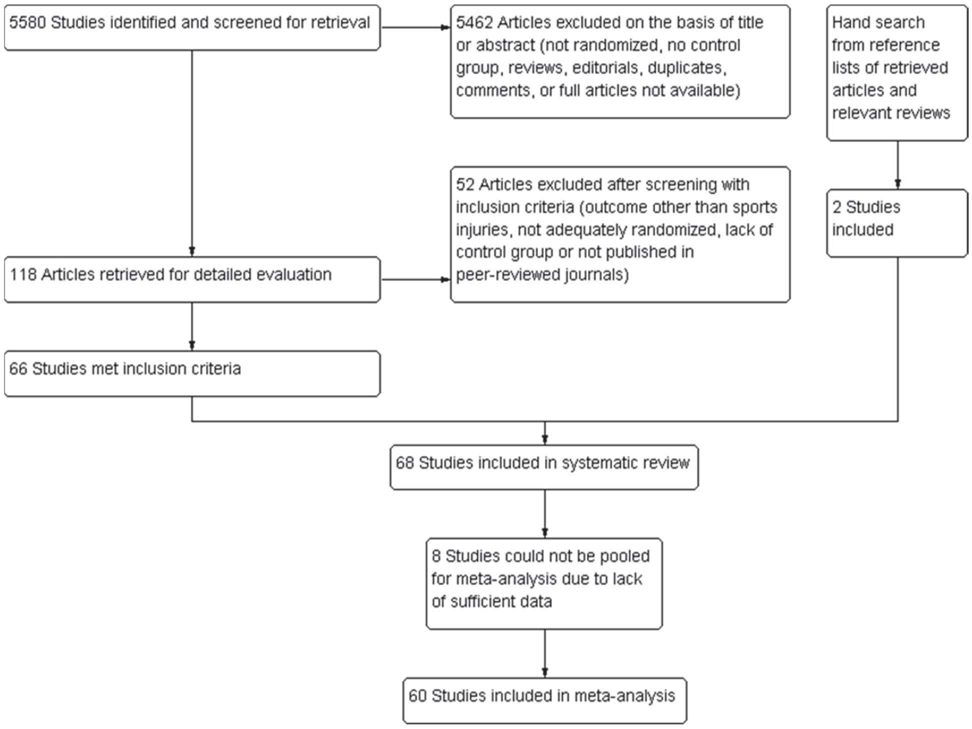

FIGURE 6 Literature search flow chart.

Inclusion criteria for the selection were such that the trials selected had to examine the effects of any preventive intervention in sports injuries, had to be randomized (or quasi-randomized) controlled trials, and published in a peer-reviewed journal. Only articles published in English were approved. Furthermore, the outcome of the trial had to include the injury rate or the number of injured individuals. In the second search, during the manual search of the reference lists of relevant reviews and retrieved articles, also articles published before 2006 were included if they met other inclusion criteria.

Studies on athletes from recreation to elite levels and from different sports disciplines as well as studies on military recruits were included. This was done in order to receive all information available.

Trials were excluded if they were not randomized, if there was no control group, if the outcome was related to injuries other than sports injuries, or if the article was not published in a peer-reviewed journal. Additionally, abstracts without the full text available were excluded. The study report had to contain adequate information about the trial protocol and the injury rate or the number of injured individuals as an outcome. One article was excluded because the article had been retracted afterwards on the basis of ethical reasons.

Data extraction was performed based on the full text version of each included study. In cases where articles provided insufficient data, the authors were contacted via email. Extracted information included the study design, description of the intervention, characteristics of participants, and the main outcomes from each article. Detailed information regarding the characteristics of the trials included is presented in Appendix I.

4.2.3 Methodological quality assessment of the selected studies

The methodological quality of the included trials was assessed according to Furlan et al. (2009). The quality assessment list consists of 12 criteria: method of randomization, concealed allocation, blinding of participants, blinding of care providers, blinding of outcome assessors, drop-out rate, analysis according to allocated group, reporting without selective outcome, baseline similarity of the groups, co-interventions, compliance, and timing of outcome assessment. Each criterion was scored as 'yes', 'unclear' or 'no', with 'yes' indicating one point.

The studies were rated as having a low risk of bias when at least six out of twelve points were scored, and the study had no other serious flaws (e.g. high drop-out rate in one group or a compliance threshold of less than 50% of the criteria) (Furlan et al. 2009). Studies were rated as having a high risk of bias if fewer than six points were scored, or if a study had one or more serious flaws. Studies were not excluded due to low scores on methodological quality.

4.2.4 Statistical analyses

Calculations for the meta-analysis were made with Cochrane Collaboration Review Manager 5.1 software. All calculations were made according to the primary outcomes of the studies. The calculations were primarily based on the number of injured individuals in the intervention group and in the control group. If the number of injured individuals was not available, the number of injuries was used instead. Odds ratios (OR) with 95% confidence intervals (CI) were used as the effect measure, the statistical method was inverse variance, and the analysis model was based on random effects. Statistical heterogeneity (I^2) and test for overall effect was calculated and P values of less than 0.05 were regarded as significant.

4.3 Part 2: Epidemiology and risk factors of injuries

4.3.1 Study design and participants

The second part of the dissertation contains data from the PROFITS (Predictors of Lower Extremity Injuries in Team Sports) study (Pasanen et al. 2015). The PROFITS study is a 4.5-year prospective cohort study aiming to investigate risk factors for lower extremity injuries in young team sports athletes. The data used in the current dissertation were collected during the first data collection period (from May 2011 to April 2014).

Participants were recruited from six basketball and floorball clubs of the Tampere subregion, Finland (Figure 7). Each study year (2011, 2012, and 2013), players from the two highest junior league levels were invited to participate. Players who were junior-aged (U21) and official members of the participating teams were eligible for participation. Final participation was based on a written informed consent form from the player (including parental consent for players under 18 years).

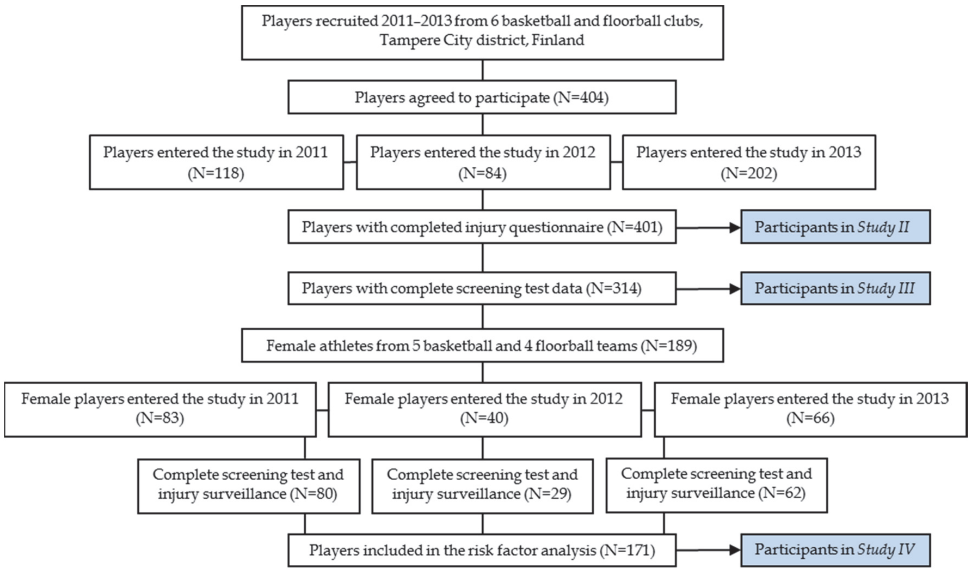

FIGURE 7 The flow of participants.

At the beginning of each study year, participating players were examined with a test battery, including questionnaires and physical tests at the UKK Institute, Tampere, Finland. After the baseline screening tests that took place in April–May, players were followed 12 months for all time-loss injuries and exposure data. Each spring, new players entered the study and the previously participating players were encouraged to continue in the follow-up. Thus, the total length of the follow-up was 12 to 36 months depending on the starting year.

A total of 404 basketball and floorball players (aged 12–21 years) volunteered to participate. Of these players, 118 players entered the study in 2011, 84 players in 2012, and 202 players in 2013. The study groups in the three individual articles based on the PROFITS study are not identical because of the nature of the collected data (Table 4).

TABLE 4 Characteristics of subjects.

	Study II	*Study III*	*Study IV*
N	401	314	171
Male (n)	213	153	-
Female (n)	188	161	171
Basketball (n)	207	173	96
Floorball (n)	194	141	75
Age (years)	15.8 ± 1.9	15.7 ± 1.8	15.4 ± 1.9
Height (cm)	173.7 ± 9.2	173.2 ± 9.2	167.7 ± 6.2
Weight (kg)	65.7 ± 11.0	64.6 ± 10.4	60.8 ± 8.0
BMI (kg/m^2)	21.7 ± 2.8	21.5 ± 2.6	21.6 ± 2.4

BMI = body mass index

Of the 404 basketball and floorball players who initially participated in the study, 90 players were excluded from the analysis in Study III. The reasons for exclusion of players were as follows: players did not participate in the test due to ongoing injury or illness (57 players) or the performed testing data was invalid (33 players). The test was regarded as invalid due to gaps in marker trajectories that could not be interpolated. In most of these cases, the ASIS (anterior superior iliac spine) markers were occluded by the player's upper body in the bottom phase of the jump (due to a deep landing strategy).

For the risk factor analysis, only female players were selected. Complete data for the baseline screening tests as well as the prospective registration of injury and match/training exposure were obtained from 171 athletes. Of the females in the current investigation, 80 players entered the study in 2011, 29 in 2012, and 62 in 2013 (Figure 7). Following the start of screening tests, the players were followed for new ACL injuries through April 2014.

4.3.2 Retrospective data collection

The data in Study II is based on a detailed questionnaire, which subjects completed when they entered the study. The questionnaire was based on a previous study of sports injuries (Pasanen et al. 2008a), and covered information on personal data, sports participation and the history of sports injuries. The athletes were asked to evaluate as precisely as possible the number of weekly training sessions, the number of hours spent per session, and the number of games they played during previous season. One part of the questionnaire concerned injury occurrence during participation in the player's sport. This part was completed if the athlete had sustained a sports injury in the preceding 12 months. For each injury that had occurred over the period of interest, the anatomical location, the injury type, the beginning of the injury (acute or overuse), the context (contact or non-contact, training or competition), the date of occurrence and the recovery time were registered. The collected data were systematically cross-checked with the athlete face-to-face to ensure the accuracy of the completed questionnaire.

The self-reported overuse injury occurrence was analyzed over a preceding 12-month period. The total hours of exposure were calculated as the sum of the training and game hours per year. The total training hours per year for each player were calculated by the individually reported weekly training hours over the 45-week active period. Total exposure time during the games was calculated using an average of 60 minutes of active exposure time (including time spent in warm-up, playing and cool-down) per game per player.

4.3.3 Screening test protocol

At the beginning of each study year, participants underwent a series of screening tests performed in a 3D motion analysis laboratory. A vertical drop jump task was selected as the test of interest for the current dissertation. The testing protocol was adapted from the risk factor study by Nilstad et al. (2014b).

During the test the players wore indoor sports shoes and tight shorts. Female players wore a sports bra and male players were shirtless. Height and weight as well as knee and ankle joint widths were measured before the test. Sixteen reflective markers were placed over anatomical landmarks on the lower extremities (Figure 8) according to the Plug-In Gait marker set (Vicon Nexus v1.7; Oxford Metrics, Oxford, UK). A study assistant carefully palpated the landmarks and placed the markers over the following anatomical places bilaterally: on the shoe over the second metatarsal head and over the posterior calcaneus, lateral malleolus, lateral shank, lateral knee, lateral thigh, anterior superior iliac spine, and posterior superior iliac spine. Prior to the drop jump task, the subjects had performed a standardized warm-up procedure, which included 5 minutes of bicycling and other physical tests.

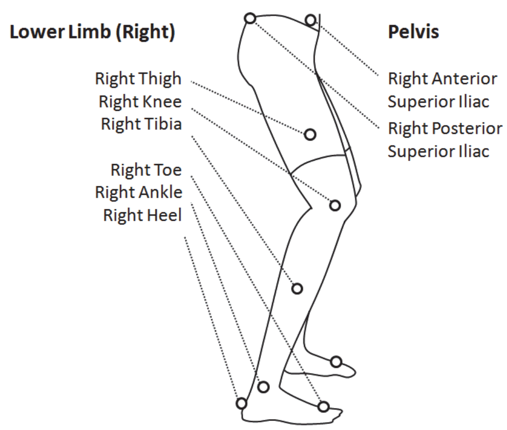

FIGURE 8 Marker placement (right side of the body) according to lower limb Plug-In gait model (Vicon, Oxford, UK).

Players were instructed to drop off a 30-cm box and perform a maximal jump upon landing with their feet on two separate force platforms (AMTI BP6001200; AMTI, Watertown, MA). Participants were allowed to practice the task up to three times. Three successful trials were collected from each participant. A trial was considered valid if the participant landed with one foot on each of the adjacent force platforms, performed a maximal vertical jump after the first landing, and the markers stayed firmly on the skin and were visible for cameras throughout the task.

Eight high-speed cameras (Vicon T40, Vicon) and two force platforms (AMTI BP6001200; AMTI, Watertown, MA) were used to record marker positions and ground reaction force data synchronously at 300 and 1500 Hz, respectively. A static calibration trial was completed prior to the task to determine the anatomical segment coordinate systems. Marker trajectories were identified with the Vicon Nexus software (Vicon Nexus v1.7; Oxford Metrics). Both movement and ground reaction force were filtered using a fourth-order Butterworth filter with cutoff frequencies of 15 Hz (Kristianslund, Krosshaug & van der Bogert 2012). The landing phase was defined as the period when the unfiltered ground reaction force exceeded 20 N.

4.3.4 Motion data analyses

Data analyses were performed using the Plug-in Gait model (Vicon Nexus v1.7, Oxford Metrics). Interpolation using the Pattern Fill algorithm was performed if the markers disappeared momentarily (time period of 25 frames or less). Trials were excluded if the reflective markers were out of sight for longer than 25 frames. An inverse dynamics approach according to the Plug-in Gait model was used to calculate knee joint moments.

Knee joint kinematics and kinetics during the first landing phase of the drop jump were determined across three successful trials. A positive value in knee flexion corresponds to a flexed knee (Figure 9B). Knee valgus angle was defined as positive and knee varus as negative (Figure 9A). Positive knee abduction moment corresponds to external abduction moment, which tends to abduct the knee.

Medial knee displacements (MKD) were calculated from the 3D marker trajectories using a custom Matlab script (MathWorks Inc., Natick, Massachusetts, USA). The medial knee position was defined as the perpendicular distance from the knee joint center to the line determined by the hip and ankle joint centers in the frontal plane. The value of the medial knee position was determined to be positive only if the knee joint center was medially positioned to the line spanned by the hip and ankle joint centers. Otherwise, the medial knee position was set to zero. The medial knee displacement was then calculated as the difference between the medial knee position at its peak value and the initial foot contact.

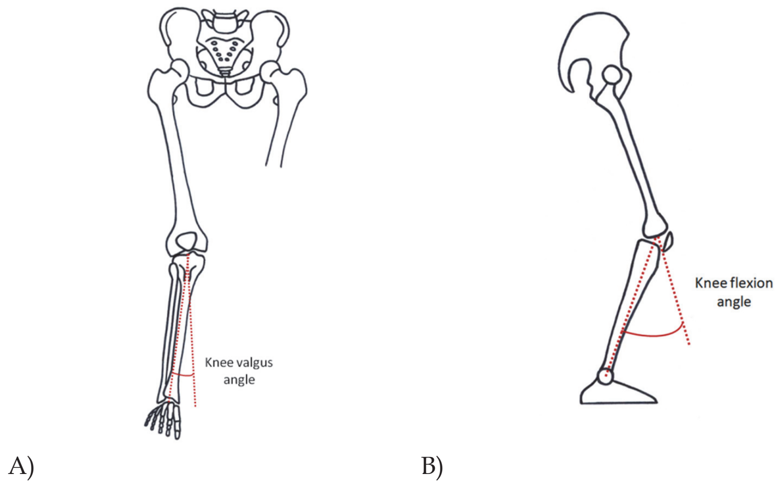

FIGURE 9 A) Knee valgus angle and B) Knee flexion angle.

In Study III, peak knee valgus angles and peak knee flexion angles during the landing phase were selected for analyses (Table 5). Both legs were analyzed and the mean angle for each trial was calculated and used in the analyses. Based on the average values of three trials for each subject, frontal plane knee control was classified as good (varus angles > 0.0°), reduced (valgus angles ranging between -0° and -10°) or poor (valgus angles < -10.0°) [modified according to Fox et al. (2014) and Nilstad et al. (2014a)].

TABLE 5 Biomechanical variables.

Variables of valgus loading	Unit	Interpret	*Study III*	*Study IV*
Valgus angle (peak)	degree (°)	pos. -> valg. neg. -> var.	mean, legs combined	-
Valgus angle at IC	degree (°)	pos. -> valg. neg. -> var.	-	mean, legs separately
Abduction moment	Newton meter (Nm)	pos. -> ext. moment	-	mean, legs separately
MKD	millimeter (mm)	pos. -> medial movement other -> 0	-	mean, legs separately
Variables of landing stiffness	**Unit**	**Interpret**	***Study III***	***Study IV***
Flexion angle (peak)	degree (°)	pos.	mean, legs combined	mean, legs separately
Flexion angle at IC	degree (°)	pos.	-	mean, legs separately
Vertical GRF	Newton (N)	pos.	-	mean, legs separately

IC = initial contact; MKD = medial knee displacement; pos. = positive value; neg. = negative value; valg. =valgus alignment; var. = varus alignment.

4.3.5 Candidate risk factors

For each participant, six pre-defined biomechanical variables were calculated during the contact phase of the VDJ task. The following candidate risk factors were selected based on the current literature on factors associated with ACL injuries: (1) knee valgus angle at initial contact (IC), (2) peak knee abduction moment, (3) knee flexion angle at IC, (4) peak knee flexion angle, (5) peak vertical ground reaction force, and (6) medial knee displacement.

4.3.6 Prospective injury and exposure registration

During the prospective study period, five study physicians contacted the teams once a week to check for possible new injuries. After each reported injury a study physician interviewed the injured player using a structured questionnaire. The definition of a new ACL injury was an MRI confirmed ACL rupture that occurred during a match or scheduled team training. Only noncontact and indirect contact injuries (i.e. no direct contact or strike to the involved knee) were included. A previous ACL injury was defined as an ACL injury of the ipsilateral or contralateral leg, from which the player had fully recovered and had returned to sport before entering the study.

Exposure time during training and games was collected on a monthly basis. The coaches recorded player participation in practices and games using a structured team diary.

4.3.7 Statistical analyses

Statistical analyses were conducted in SPSS for Windows (v 20.0.0, SPSS Inc., Chicago, Illinois, USA), except the regression analysis, which was conducted in R (v 3.1.2, R Foundation for Statistical Computing, Vienna, Austria).

Means ± SD were calculated to describe continuous variables, and frequencies and percentages were used for categorical variables. Group differences were analyzed using the Chi-square test (categorical variables) and the independent samples *t* test (continuous variables). *P* values less than 0.05 were considered significant.

In Study III, a multivariate analysis of variance with age as a covariant was used to determine the effect of gender (male vs. female) and sport (basketball vs. floorball) on peak knee valgus angle and peak knee flexion angle.

Injury rate was calculated as the number of injured players divided by the number of exposed players. Injury incidence was calculated as the number of injuries per 1,000 player hours and reported with 95% confidence intervals (CI) [(incidence rate - 1.96 x standard error of incidence rate) x 1 000 hours to (incidence rate + 1.96 x standard error of incidence rate) x 1 000 hours]. For measures of relative correlation between outcome variables, the Spearman correlation coefficient was calculated.

For the risk factor analysis, six separate Cox mixed-effects models (Therneau 2015) with a new non-contact ACL injury as the outcome and the leg as a unit of analysis were generated. The monthly exposure time from the start of the prospective follow up until the first ACL injury or the end of the follow-up was included in the regression models. The mean of three jump trials was used for each biomechanical variable. Pre-defined adjustment factors that might influence the risk of injury were included in all six models: age, height, weight, sport, dominant leg, participation in adult league level matches, and previous ACL injury (a total of four previous injuries). Sports club and leg were included in all models as random effects. The leg preferred when kicking a ball was defined as the dominant leg. Cox hazard ratios with 95% confidence intervals (CI) were calculated for ten or hundred unit change.

A receiver operating characteristic (ROC) curve was calculated to investigate the sensitivity and specificity characteristics of a test based on the peak knee flexion and vertical GRF variables. The test outcome was defined as excellent (an area under the curve of 0.90–1), good (0.80–0.89), fair (0.70–0.79), poor (0.60–0.69), and fail (0.50–0.59).

5 RESULTS

5.1 Effectiveness of injury prevention interventions (Study I)

Altogether, 68 randomized controlled trials examining the effects of preventive intervention on sports injuries were discovered through a systematic literature search. The average methodological quality score received was 5/12 (range 2 to 9 out of 12 points). The detailed results of the methodological quality assessment are presented in the Appendix II.

Trials were divided into seven groups (training programs, insoles, external joint supports, stretching, protective head equipment, modified shoes, and injury prevention videos) according to the type of the intervention. Some groups were further divided into subgroups according to intervention characteristics. This was done even though there might have been some heterogeneity in interventions and in methodological issues between the studies. Five studies (Barrett et al. 1993, McIntosh et al. 2009, Mohammadi 2007, Smith, Walter & Bailey 1985, Tropp, Askling & Gillquist 1985) had two or more intervention groups tested, but only one control group. These interventions were pooled as individual trials. Seven of the included studies (Bello et al. 2011, Finch et al. 2005, Finestone et al. 1992, Finestone et al. 2004, Gabbe, Branson & Bennell 2006, Kinchington, Ball & Naughton 2011, Larsen, Weidich & Leboeuf-Yde 2002) could not be pooled due to insufficient injury data. In addition, one trial (Lappe et al. 2008) could not be pooled to any subgroup of trials due to its unique intervention on dietary supplements.

5.1.1 Training interventions

The effects of physical training on sports injury prevention were studied in 38 of the included trials. Characteristics of included studies on training interventions are presented in Appendix I. Training interventions were divided into six subgroups: balance board training, multi-intervention with balance board training, other multi-interventions, warm-up programs, strength training, and graded running programs (Figure 10).

Balance board training (7 studies, 1,922 subjects) appeared to be effective in reducing the number of sports injuries in the intervention group compared to the control group (pooled OR 0.45, 95% CI 0.28 to 0.73). The results showed heterogeneity ($I^2 = 61\%$, $P = 0.02$). Furthermore, examination of the studies investigating a multi-intervention with balance board training (7 studies, 3,458 subjects) yielded consistent results (pooled OR 0.46, 95% CI 0.31 to 0.64). Other multi-intervention studies (9 studies, 5,429 subjects) also achieved preventive effects (pooled OR 0.63, 95% CI 0.42 to 0.95), but more inconsistency in the results as well as strong heterogeneity ($I^2 = 84\%$, $P < 0.001$) were observed.

The effectiveness of a warm-up program was studied in eight trials (13,817 subjects). Half of these trials found significant preventive effect (ORs from 0.29 to 0.92). The pooled result supported that warm-up programs can reduce the risk of sports injuries (pooled OR 0.64, 95% CI 0.49 to 0.83). There was a statistically significant heterogeneity ($I^2 = 66\%$, $P < 0.01$).

Four studies (1,232 subjects) assessed the effects of strength training on lower extremity injuries. According to two of these studies, eccentric strength training was effective in reducing the risk of hamstring injuries among football players (Askling, Karlsson & Thorstensson 2003, Petersen et al. 2011). One study (Mohammadi 2007) found no significant effect of strength training on the recurrence of ankle sprain. The pooled analysis confirmed that strength training has a preventive effect (pooled OR 0.27, 95% CI 0.16 to 0.45). No heterogeneity was observed ($I^2 = 0\%$, $P = 0.59$). The results of the study by Gabbe, Branson & Bennell (2006) could not be pooled, but no differences were found in the rates of hamstring injuries between the intervention and control group (RR 1.2, 95% CI 0.5 to 2.8).

Two studies (Bredeweg et al. 2012, Buist et al. 2008) on the effects of a graded training program in the prevention of running related injuries among novice runners (848 subjects) failed to show any preventive effects (pooled OR 0.97, 95% CI 0.69 to 1.38; $I^2 = 0\%$, $P = 0.69$).

According to the pooled results from 37 trials, training interventions were effective in reducing the risk of sports injuries (pooled OR 0.55, 95% CI 0.46 to 0.66). Heterogeneity between the studies was marked ($I^2 = 75\%$, $P < 0.001$) (Figure 10).

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
3.1.1 Balance board training						
Emery et al. 2005	2	66	10	61	1.0%	0.16 [0.03, 0.76]
Hupperets et al. 2009	56	256	89	266	3.8%	0.56 [0.38, 0.82]
Mohammadi 2007	1	20	8	20	0.6%	0.08 [0.01, 0.71]
Söderman et al. 2000	23	62	25	78	2.7%	1.25 [0.62, 2.52]
Tropp et al. 1985b	7	142	30	171	2.2%	0.24 [0.10, 0.57]
Verhagen et al. 2004	29	392	41	340	3.4%	0.58 [0.35, 0.96]
Wester et al. 1996	6	24	13	24	1.4%	0.28 [0.08, 0.96]
Subtotal (95% CI)		**962**		**960**	**15.0%**	**0.45 [0.28, 0.73]**
Total events	124		216			
Heterogeneity: Tau² = 0.22; Chi² = 15.37, df = 6 (P = 0.02); I² = 61%						
Test for overall effect: Z = 3.20 (P = 0.001)						
3.1.2 Multi-intervention with balance board training						
Eils et al. 2010	7	81	21	91	2.1%	0.32 [0.13, 0.79]
Emery & Meeuwisse 2010	48	380	70	364	3.7%	0.61 [0.41, 0.91]
Emery et al. 2007	130	494	141	426	4.1%	0.72 [0.54, 0.96]
McGuine & Keene 2006	23	373	39	392	3.2%	0.59 [0.35, 1.02]
Pasanen et al. 2008	20	256	40	201	3.1%	0.34 [0.19, 0.60]
Wedderkopp et al 1999	11	111	45	126	2.6%	0.20 [0.10, 0.41]
Wedderkopp et al. 2003	6	77	16	86	1.9%	0.37 [0.14, 1.00]
Subtotal (95% CI)		**1772**		**1686**	**20.7%**	**0.46 [0.32, 0.64]**
Total events	245		372			
Heterogeneity: Tau² = 0.12; Chi² = 16.27, df = 6 (P = 0.01); I² = 63%						
Test for overall effect: Z = 4.46 (P < 0.00001)						
3.1.3 Other multi-interventions						
Brushøj et al. 2008	108	507	91	513	4.0%	1.26 [0.92, 1.71]
Collard et al. 2010	100	1015	104	996	4.1%	0.94 [0.70, 1.25]
Ekstrand et al. 1983	23	90	62	90	2.8%	0.16 [0.08, 0.30]
Engebretsen et al. 2008	114	193	114	195	3.7%	1.03 [0.68, 1.54]
Heidt et al. 2000	6	42	87	258	2.1%	0.33 [0.13, 0.81]
Holme et al. 1999	2	29	11	38	1.0%	0.18 [0.04, 0.90]
Hägglund et al. 2007	10	90	23	79	2.3%	0.30 [0.13, 0.69]
Parkkari et al. 2011	114	501	120	467	4.1%	0.85 [0.63, 1.14]
van Mechelen et al. 1993	24	159	20	167	2.9%	1.31 [0.69, 2.47]
Subtotal (95% CI)		**2626**		**2803**	**27.1%**	**0.63 [0.42, 0.95]**
Total events	501		632			
Heterogeneity: Tau² = 0.28; Chi² = 49.37, df = 8 (P < 0.00001); I² = 84%						
Test for overall effect: Z = 2.21 (P = 0.03)						
3.1.4 Warm-up programs						
Gilchrist et al. 2008	2	583	10	852	1.0%	0.29 [0.06, 1.33]
LaBella et al. 2011	47	737	83	755	3.8%	0.55 [0.38, 0.80]
Longo et al. 2012	14	80	17	41	2.2%	0.30 [0.13, 0.70]
Olsen et al. 2005	46	958	76	879	3.8%	0.53 [0.37, 0.78]
Soligard et al. 2008	121	1055	143	837	4.2%	0.63 [0.48, 0.82]
Steffen et al. 2008	204	1073	192	947	4.3%	0.92 [0.74, 1.15]
van Beijsterveldt et al.	135	223	139	233	3.8%	1.04 [0.71, 1.51]
Waldén et al. 2012	7	2479	14	2085	2.1%	0.42 [0.17, 1.04]
Subtotal (95% CI)		**7188**		**6629**	**25.3%**	**0.64 [0.49, 0.83]**
Total events	576		674			
Heterogeneity: Tau² = 0.08; Chi² = 20.81, df = 7 (P = 0.004); I² = 66%						
Test for overall effect: Z = 3.39 (P = 0.0007)						
3.1.5 Strenght training						
Askling et al. 2003	3	15	10	15	0.9%	0.13 [0.02, 0.66]
Mohammadi 2007	4	20	8	20	1.2%	0.38 [0.09, 1.54]
Petersen et al. 2011	15	461	52	481	3.0%	0.28 [0.15, 0.50]
Subtotal (95% CI)		**496**		**516**	**5.1%**	**0.27 [0.16, 0.45]**
Total events	22		70			
Heterogeneity: Tau² = 0.00; Chi² = 1.04, df = 2 (P = 0.59); I² = 0%						
Test for overall effect: Z = 5.00 (P < 0.00001)						
3.1.6 Graded running program						
Bredeweg et al. 2012	26	171	32	191	3.1%	0.89 [0.51, 1.57]
Buist et al. 2008	52	250	48	236	3.6%	1.03 [0.66, 1.60]
Subtotal (95% CI)		**421**		**427**	**6.7%**	**0.97 [0.69, 1.38]**
Total events	78		80			
Heterogeneity: Tau² = 0.00; Chi² = 0.15, df = 1 (P = 0.69); I² = 0%						
Test for overall effect: Z = 0.15 (P = 0.88)						
Total (95% CI)		**13465**		**13021**	**100.0%**	**0.55 [0.46, 0.66]**
Total events	1546		2044			
Heterogeneity: Tau² = 0.17; Chi² = 138.26, df = 35 (P < 0.00001); I² = 75%						
Test for overall effect: Z = 6.60 (P < 0.00001)						
Test for subgroup differences: Chi² = 20.77, df = 5 (P = 0.0009), I² = 75.9%						

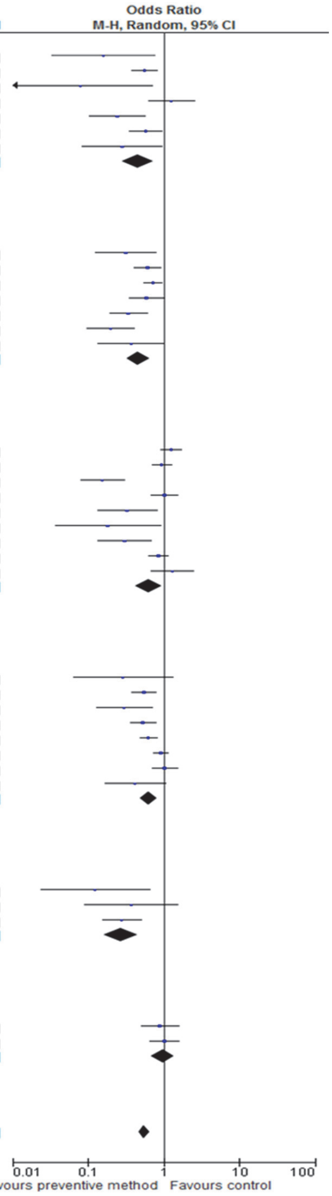

FIGURE 10 Training programs vs. control. OR (blue boxes), pooled OR (black diamonds), 95% confidence intervals, and test of heterogeneity.

5.1.2 Insoles

The effects of insoles to reduce the risk of lower limb injuries among military recruits were studied in nine trials (4,788 subjects). Combined results from eight trials showed that insoles significantly reduced the risk of injuries (pooled OR 0.51, 95% CI 0.32 to 0.81). There was a strong heterogeneity between the studies (I^2 = 82%, P < 0.001) (Figure 11). Two studies (Finestone et al. 2004, Larsen, Weidich & Leboeuf-Yde 2002) could not be pooled; no significant risk reduction was observed in these studies.

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Odds Ratio IV, Random, 95% CI
1.1.1 Insoles						
Finestone et al. 1999	16	126	19	71	12.0%	0.40 [0.19, 0.84]
Franklyn-Mill et al. 2011	21	200	61	200	14.0%	0.27 [0.16, 0.46]
Mattila et al. 2011	34	73	56	147	13.8%	1.42 [0.80, 2.50]
Milgrom et al. 1985	33	113	70	152	14.3%	0.48 [0.29, 0.81]
Schwellnus et al. 1990	49	237	317	1151	15.9%	0.69 [0.49, 0.96]
Smith et al. 1985	6	23	15	24	7.7%	0.21 [0.06, 0.74]
Smith et al. 1985b	3	21	15	24	6.3%	0.10 [0.02, 0.44]
Withnall et al. 2006	149	805	72	401	16.1%	1.04 [0.76, 1.42]
Subtotal (95% CI)		**1598**		**2170**	**100.0%**	**0.51 [0.32, 0.81]**
Total events	311		625			
Heterogeneity: Tau² = 0.32; Chi² = 38.41, df = 7 (P < 0.00001); I² = 82%						
Test for overall effect: Z = 2.83 (P = 0.005)						
Total (95% CI)		**1598**		**2170**	**100.0%**	**0.51 [0.32, 0.81]**
Total events	311		625			
Heterogeneity: Tau² = 0.32; Chi² = 38.41, df = 7 (P < 0.00001); I² = 82%						
Test for overall effect: Z = 2.83 (P = 0.005)						
Test for subgroup differences: Not applicable						

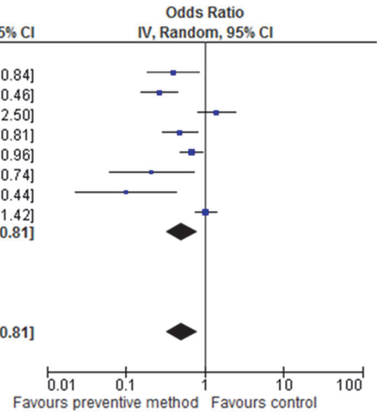

FIGURE 11 Insoles vs. control. OR (blue boxes), pooled OR (black diamonds), 95% confidence intervals, and test of heterogeneity.

5.1.3 External joint supports

Studies on external joint supports (10 studies, 13,808 subjects) were further divided on ankle, wrist and knee supports. Ankle supports (7 studies, 6,662 subjects) reduced ankle injuries compared to no ankle supports (pooled OR 0.40, 95% CI 0.30 to 0.53) (Figure 12).

According to two trials (5,750 subjects), wrist supports were effective in protecting snowboarders against wrist injury (pooled OR 0.25, 95% CI 0.12 to 0.51). In addition, the use of prophylactic knee braces significantly reduced the number of knee injuries among 1,396 military cadets while playing football (OR 0.43, 95% CI 0.24 to 0.78). The pooled analysis of external joint supports showed significant preventive effect (pooled OR 0.39, 95% CI 0.31 to 0.49). Statistical heterogeneity between the studies was low ($I^2 = 13\%$, $P = 0.32$).

5.1.4 Stretching

Combined results from the studies on stretching (four studies, 4,812 subjects) showed no effect on the rate of injuries (pooled OR 0.92, 95% CI 0.80 to 1.06) (Figure 13). No statistical heterogeneity between the studies was observed. The findings from Bello et al. (2011) could not be pooled, but the results showed no differences in injury rates between the intervention (rhythmic stabilization method) and the control group (normal stretching).

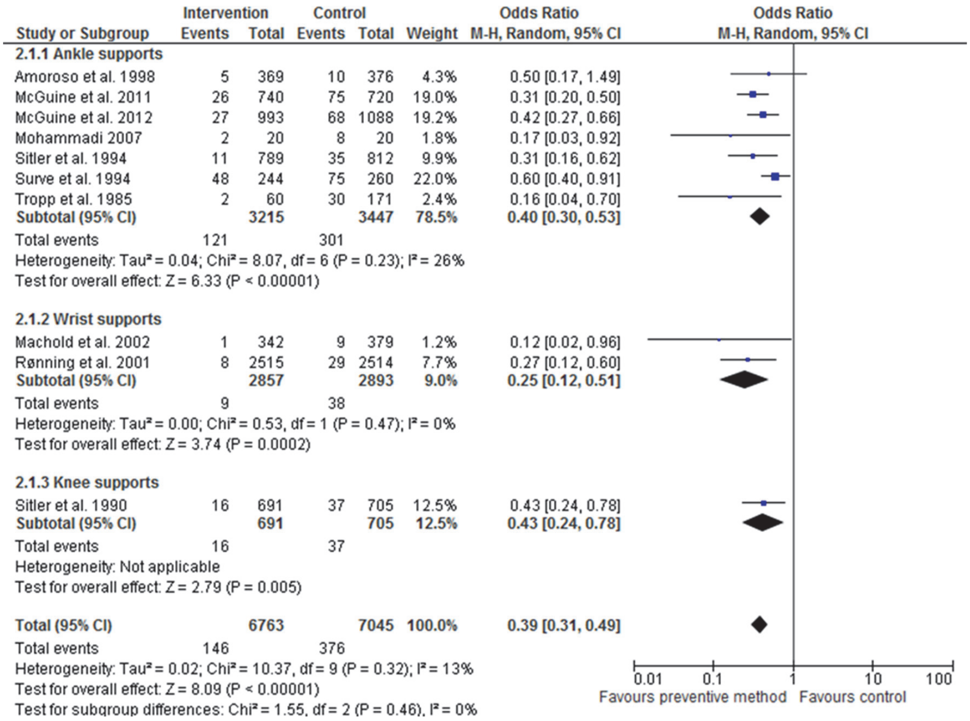

FIGURE 12 External joint supports vs. control. OR (blue boxes), pooled OR (black diamonds), 95% confidence intervals, and test of heterogeneity.

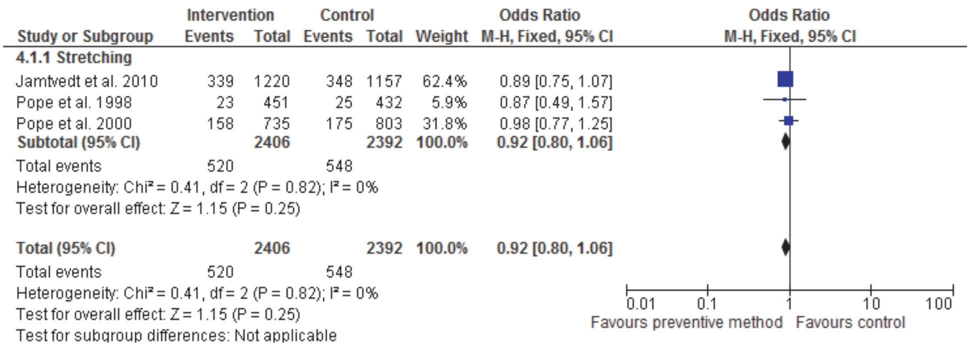

FIGURE 13 Stretching vs. control. OR (blue boxes), pooled OR (black diamonds), 95% confidence intervals, and test of heterogeneity.

5.1.5 Other interventions

The effects of protective head equipment (including headgears and mouth guards) on head injuries or concussions were studied in three trials (5,010 subjects) with four different comparisons. The pooled results showed no significant preventive effects (pooled OR 1.06, 95% CI 0.91 to 1.24) (Figure 14).

The results of the study by Finch et al. (2005) with 301 Australian football players could not be pooled, but found that custom-made mouth guards significantly reduced the rates of head and orofacial injuries in the intervention group compared to the control group (RR 0.56, 95%CI 0.32 to 0.97).

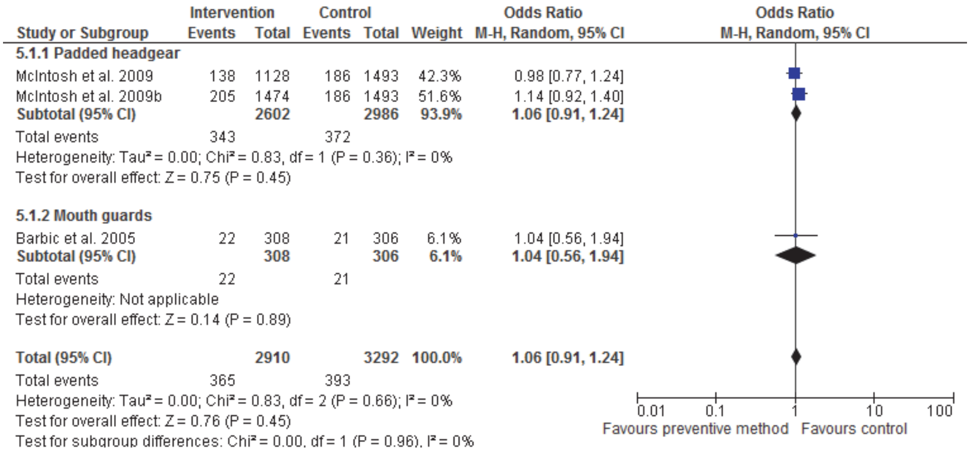

FIGURE 14 Protective head equipment vs. control. OR (blue boxes), pooled OR (black diamonds), 95% confidence intervals, and test of heterogeneity.

The effects of modified shoes on lower limb injuries were studied in four trials with five different interventions (1,408 subjects) (Figure 15). Three different types of basketball shoes were tested (Barrett et al. 1993, Milgrom et al. 1992), and the modified shoes had no effect on injury rates (pooled OR 1.23, 95% CI 0.81 to 1.87). In addition, two studies could not be pooled. In the study by Finestone et al. (1992), no group differences were observed, but the results of the study by Kinchington, Ball & Naughton (2011) investigating the effects of a tailored footwear program, favored the intervention group.

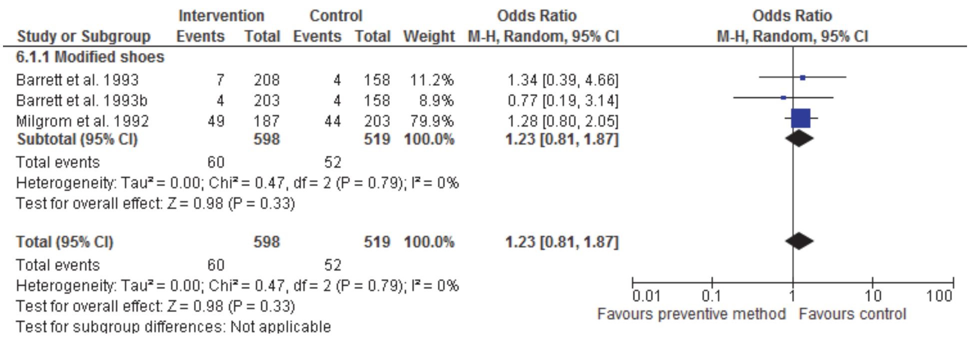

FIGURE 15 Modified shoes vs. control. OR (blue boxes), pooled OR (black diamonds), 95% confidence intervals, and test of heterogeneity.

The combined effects of the injury prevention videos (three studies, 1,103 subjects) were not significant (pooled OR 0.86, 95% CI 0.44 to 1.68) (Figure 16). Finally, the results from one study investigating the effects of dietary supplements among female military recruits (5,201 subjects) showed that calcium and vitamin D supplements were effective in reducing the incidence of stress fractures (OR 0.80, 95% CI 0.67 to 0.97) (Lappe et al. 2008).

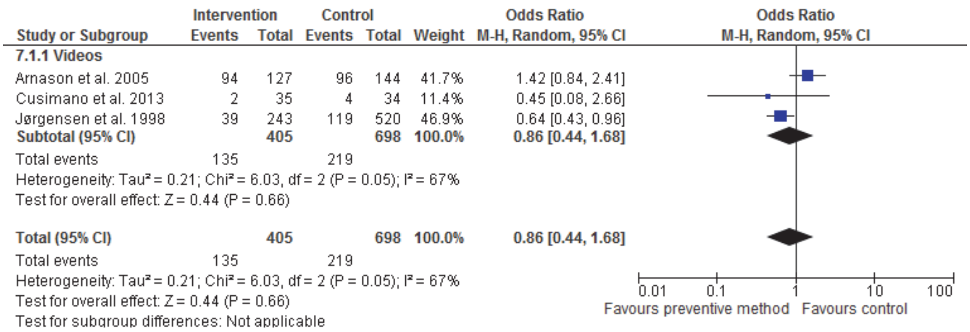

FIGURE 16 Injury prevention videos vs. control. OR (blue boxes), pooled OR (black diamonds), 95% confidence intervals, and test of heterogeneity.

5.2 Epidemiology of overuse injuries (Study II)

5.2.1 Overall player and injury characteristics

A total of 401 players completed the questionnaire in the year they entered the study. The characteristics of the participants are shown in Table 6. The male athletes were significantly older than females (P = 0.001). The males reported having started playing at a significantly (P < 0.001) younger age than the females (8.1 ± 2.6 years vs. 9.1 ± 2.7 years). The average training volume per week was significantly (P = 0.001) higher for the males (10.2 ± 3.9 h/week) than the females (9.0 ± 3.0 h/week).

Participating players reported having sustained a total of 629 injuries during the previous 12 months period. Of these injuries, 439 were acute (70%) and 190 overuse injuries (30%). The proportion of overuse injuries was 31% in basketball and 30% in floorball. The incidence of overuse injury was similar in the two sports (1.0 overuse injuries per 1,000 hours of exposure in both sports).

Of all the players who reported overuse injuries, 91 were male (60%) and 61 (40%) were female, and 80 (53%) were basketball and 72 (47%) were floorball players. In addition to time-loss injuries, participating players reported a total of 150 overuse conditions that caused no time-loss from training or competition; these were not included in the present analysis.

TABLE 6 Detailed characteristics of the participants in Study II.

	Basketball (n=207)		Floorball (n=194)		All (n=401)		
	Male (n=101)	Female (n=106)	Male (n=112)	Female (n=82)	Male (n=213)	Female (n=188)	*P* value*
Age (years)	15.2 ± 1.6	14.6 ± 1.6	16.9 ± 1.3	16.6 ± 2.0	16.1 ± 1.7	15.5 ± 2.0	*0.001*
Height (cm)	179.3 ± 9.4	168.5 ± 6.7	178.6 ± 6.5	166.5 ± 5.7	179.0 ± 8.0	167.6 ± 6.3	< *0.001*
Weight (kg)	68.9 ± 13.2	61.1 ± 9.9	70.4 ± 8.9	61.2 ± 7.5	69.7 ± 11.1	61.2 ± 8.9	< *0.001*
BMI (kg/m^2)	21.3 ± 3.1	21.5 ± 2.9	22.0 ± 2.4	22.1 ± 2.6	21.7 ± 2.7	21.7 ± 2.8	0.848
Age when started to play (years)	7.9 ± 2.3	8.1 ± 2.3	8.2 ± 2.9	10.4 ± 2.6	8.1 ± 2.6	9.1 ± 2.7	< *0.001*
Ever played in adult elite league level							
Yes (%)	4.0	1.9	7.1	30.5	5.6	14.4	
No (%)	96.0	98.1	92.9	69.3	94.4	85.6	
Training hours /wk	9.8 ± 3.2	8.9 ± 3.0	10.6 ± 4.4	9.1 ± 3.1	10.2 ± 3.9	9.0 ± 3.0	< *0.001*
Games /season	32.7 ± 14.8	38.1 ± 17.5	37.4 ± 15.4	35.7 ± 15.0	35.2 ± 15.3	37.1 ± 16.5	0.237

Values presented as means ± SD; BMI = body mass index; * *P* values for sex differences among all participants.

5.2.2 Overuse injuries in basketball

Of the 207 basketball players participating the study, 80 players (39%) reported having had at least one overuse injury in the preceding 12 months. The male players reported 44 (45%) overuse injuries and the female players 53 (55%), leading to a total of 97 overuse injuries among the basketball players. The overuse injury rate was 0.47 injuries per athlete per year.

Most of the overuse injuries in basketball involved the lower extremities (64 cases, 66%), with the knee being the most commonly injured site (44 cases, 45%) (Table 7). Overuse injuries caused an average time loss from full participation of 26 ± 50 days (median seven days). The severity of injuries is presented in Table 8. In basketball, there were no differences for the anatomical location (Figure 17) or the severity of overuse injuries between the genders.

TABLE 7 Distribution of overuse injuries according to anatomical location, injury severity, game and gender.

	Basketball (n=97)			Floorball (n=93)			
	Male (n=44)	Female (n=53)	All	Male (n=65)	Female (n=28)	All	Total
All	44 (16/6/6/16)	53 (21/11/10/11)	97 (37/17/16/27)	65 (30/12/16/7)	28 (11/4/11/2)	93 (41/16/27/9)	190 (78/33/43/36)
Head/neck	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)
Upper body	0 (0/0/0/0)	1 (1/0/0/0)	1 (1/0/0/0)	0 (0/0/0/0)	2 (1/1/0/0)	2 (1/1/0/0)	3 (2/1/0/0)
Trunk	15 (10/2/1/2)	17 (11/2/2/2)	32 (21/4/3/4)	32 (17/4/7/4)	8 (6/0/2/0)	40 (23/4/9/4)	72 (44/8/12/8)
Upper back/chest	0 (0/0/0/0)	1 (1/0/0/0)	1 (1/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	1 (1/0/0/0)
Lower back/pelvis	11 (7/2/1/1)	16 (10/2/2/2)	27 (17/4/3/3)	29 (16/4/6/3)	7 (5/0/2/0)	36 (21/4/8/3)	63 (38/8/11/6)
Hip/groin	4 (3/0/0/1)	0 (0/0/0/0)	4 (3/0/0/1)	3 (1/0/1/1)	1 (1/0/0/0)	4 (2/0/1/1)	8 (5/0/1/2)
Lower extremities	29 (6/4/5/14)	35 (9/9/8/9)	64 (15/13/13/23)	33 (13/8/9/3)	18 (4/3/9/2)	51 (17/11/18/5)	115 (32/24/31/28)
Thigh	0 (0/0/0/0)	1 (0/1/0/0)	1 (0/1/0/0)	6 (4/1/1/0)	0 (0/0/0/0)	6 (4/1/1/0)	7 (4/2/1/0)
Knee	22 (5/2/4/11)	22 (7/4/6/5)	44 (12/6/10/16)	25 (8/7/7/3)	7 (2/2/2/1)	32 (10/9/9/4)	76 (22/15/19/20)
Shin/calf	4 (1/1/0/2)	7 (1/2/2/2)	11 (2/3/2/4)	1 (1/0/0/0)	6 (0/0/5/1)	7 (1/0/5/1)	18 (3/3/7/5)
Ankle	1 (0/1/0/0)	4 (1/1/0/2)	5 (1/2/0/2)	1 (0/0/1/0)	2 (1/0/1/0)	3 (1/0/2/0)	8 (2/2/2/2)
Foot	2 (0/0/1/1)	1 (0/1/0/0)	3 (0/1/1/1)	0 (0/0/0/0)	3 (1/1/1/0)	3 (1/1/1/0)	6 (1/2/2/1)

n, number of injuries (minimal/mild/moderate/severe)

TABLE 8 The severity of overuse injuries (n=190) according to sports and gender, number of injuries (%).

	Basketball			Floorball		
Injury severity	Male	Female	Total	Male	Female	Total
Minimal	16 (36)	21 (40)	37 (38)	30 (46)	11 (39)	41 (44)
Mild	6 (14)	11 (21)	17 (18)	12 (19)	4 (14)	16 (17)
Moderate	6 (14)	10 (19)	16 (17)	16 (25)	11 (39)	27 (29)
Severe	16 (36)	11 (21)	27 (28)	7 (11)	2 (7)	9 (10)
Total	44 (100)	53 (100)	97 (100)	65 (100)	28 (100)	93 (100)

Injury severity: minimal = absence of 1–3 days, mild = absence of 4–7 days, moderate = absence of 8–28 days, severe = absence of ≥ 29 days.

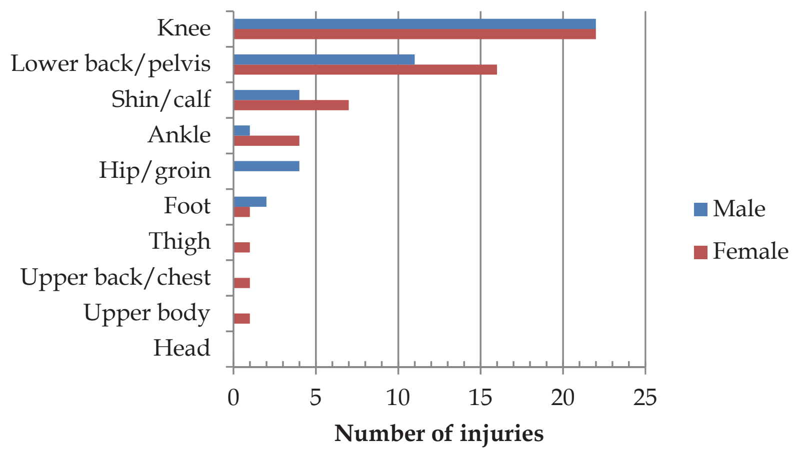

FIGURE 17 Overuse injuries in basketball according to anatomical location and gender.

5.2.3 Overuse injuries in floorball

Of the 194 floorball players, 72 players (37%) sustained at least one overuse injury in the preceding 12 months. Fifty-one male players reported overuse injury/injuries, whereas the corresponding number for female players was 21 (P = 0.005). A total of 93 overuse injuries were reported. Of these injuries the males sustained 65 (70%) and the females 28 (30%) overuse injuries. The overuse injury rate in floorball was 0.48 injuries per athlete per year.

The injuries involved the lower extremities in 55% of the cases (51 cases, 55%). The most commonly injured site was the lower back/pelvis (36 cases, 39%), and the second most common site was the knee (32 cases, 34%) (Table 7). Lower back and knee overuse injuries were more common among male floorball players than female players (P < 0.001) (Figure 18).

No differences for the severity of overuse injuries between the genders were observed ($P = 0.544$). Most of the injuries were minimal in severity (Table 8). The average time loss from full participation due to an overuse injury was 16 ± 37 days (median five days).

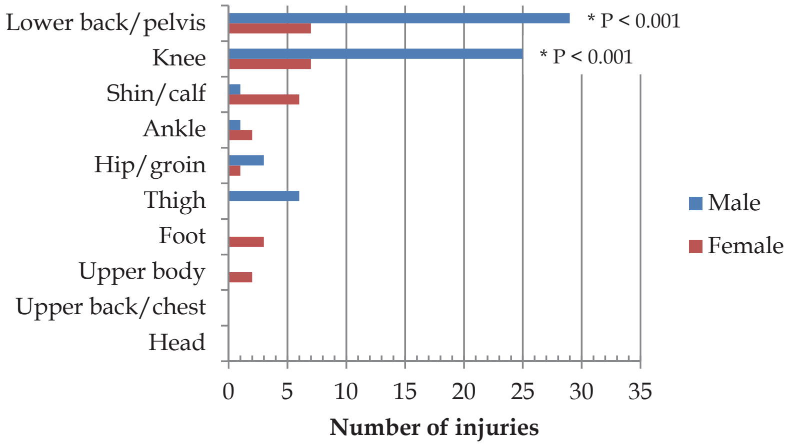

FIGURE 18 Overuse injuries in floorball according to anatomical location and gender.

5.3 Knee control and jump-landing technique (Study III)

The complete baseline screening test data from the 3D vertical drop jump task was obtained from 314 players (153 males and 161 females). The basketball players were younger than the floorball players (mean age 14.8 ± 1.6 years and 16.7 ± 1.4 years for basketball and floorball, respectively) ($P < 0.001$). There were no significant differences in height, weight or BMI between basketball and floorball players.

5.3.1 Frontal plane knee control

Mean values of the peak knee valgus/varus angles during the landing phase of the VDJ ranged from -52.9 to 14.6 degrees. Fifty-one percent of all players were categorized as having good frontal plane knee control, which indicates that nearly half of the players (49%) had difficulties in knee control. Poor knee control was observed among 21% and reduced control among the remaining 28% of the players (Table 9). There were considerable differences in knee control between the genders: 80% of the male players performed with good knee control, whereas the corresponding number was only 22% among the female players ($P < 0.001$).

TABLE 9 Frontal plane knee control according to sport and gender, n (%).

	Basketball (n=173)			Floorball (n=141)		
	Male	Female	All	Male	Female	All
Good	59 (75%)	20 (21%)	79 (46%)	64 (87%)	16 (24%)	80 (57%)
Reduced	16 (20%)	40 (43%)	56 (32%)	8 (11%)	25 (37%)	33 (23%)
Poor	4 (5%)	34 (36%)	38 (22%)	2 (3%)	26 (39%)	28 (20%)
Total	79 (100%)	94 (100%)	173 (100%)	74 (100%)	67 (100%)	141 (100%)

Knee control classified into three categories according to peak knee valgus/varus angle: good (varus angles > 0.0º), reduced (valgus angles ranging between -0º to -10º) and poor knee control (valgus angles < -10.0º).

5.3.2 Knee valgus

The basketball players exhibited significantly larger peak knee valgus angles compared with the floorball players (P = 0.022). The mean peak valgus angle (age adjusted) was -3.2º (95% CI -4.5 to -2.0) in basketball and -0.9º (95% CI -2.3 to 0.6) in floorball. Larger valgus angles were observed among the female players (-7.5º, 95% CI -8.7 to -6.2) compared with the male players (3.4º, 95% CI 2.1 to 4.6) (P < 0.001) (Table 10).

TABLE 10 Peak knee varus/valgus and flexion angles (age adjusted) according to gender and sport, mean (95% CI).

	Male (n=153)	Female (n=161)	*P* value	Basketball (n=173)	Floorball (n=141)	*P* value
Var/valg	3.4 (2.1 to 4.6)	-7.5 (-8.7 to -6.2)	*< 0.001*	-3.2 (-4.5 to -2.0)	-0.9 (-2.3 to 0.6)	*0.022*
Flex	84.5 (82.8 to 86.2)	85.1 (83.5 to 86.8)	0.607	83.1 (81.4 to 84.8)	86.5 (84.6 to 88.4)	*0.016*

Var/valg = peak knee varus/valgus angle, negative values referring to valgus and positive to varus movement; Flex = peak knee flexion angle.

5.3.3 Knee flexion

The basketball players landed with a decreased peak knee flexion angle (83.1º, 95% CI 81.4 to 84.8) compared with the floorball players (86.5º, 95% CI 84.6 to 88.4) (P = 0.016) (Table 10). There were no gender differences in the peak knee flexion angles (84.5º, 95% CI 82.8 to 86.2 for male; 85.1º, 95% CI 83.5 to 86.8 for female).

5.4 Jump-landing biomechanics and ACL injury risk (Study IV)

5.4.1 ACL injury incidence

In all, 15 new non-contact ACL injuries occurred during the three playing seasons. In addition, two contact injuries were registered but not included in the analysis. One athlete suffered two separate ACL injuries (different knees), yielding to a total of 14 injured athletes (3 basketball and 11 floorball players). Two of the injured athletes had experienced a previous ACL injury (one on the same side and one in the opposite knee). Six dominant leg and nine non-dominant leg injuries were observed.

Throughout the three seasons, a total of 58,927 hours of exposure in training and match play was registered. The overall ACL injury incidence was 0.2 injuries per 1,000 player hours (95% CI 0.1 to 0.4). Injury incidence in matches was 3.8 injuries per 1,000 hours of exposure (95% CI 1.3 to 6.3) and in training 0.1 injuries per 1,000 hours of exposure (95% CI 0.0 to 0.2). In basketball, all three ACL injuries occurred in matches (3.4 injuries per 1.000 hours of exposure). In floorball, the incidence for matches and training was 4.1 (95% CI 0.8 to 7.3) and 0.1 (95% CI 0.0 to 0.3) per 1.000 hours of exposure, respectively.

5.4.2 Biomechanical risk factors

Some significant correlations were found between the selected jump-landing variables (Table 11). The peak knee flexion angle and vertical GRF had a moderate correlation (-0.613, P < 0.001). Weak correlations existed between vertical GRF and knee valgus at IC (0.186, P = 0.001) and abduction moment (0.278, P < 0.001). No correlations were found between peak knee flexion and knee valgus angle at IC (-0.039, P = 0.47) or abduction moment (-0.068, P = 0.21).

TABLE 11 Landing biomechanics in ACL injured group and uninjured group.

Variable	ACL injured knees (n=15)	Uninjured knees (n=327)	*P* value
Knee valgus at IC (degree)*	0.9 ± 5.8	-1.8 ± 6.7	0.12
Peak knee abduction moment (Nm)	37.1 ± 24.9	31.2 ± 22.0	0.32
Medial knee displacement (mm)	22 ± 18	26 ± 20	0.47
Knee flexion at IC (degree)	30.2 ± 11.7	27.6 ± 9.0	0.29
Peak knee flexion (degree)	81.5 ± 10.0	84.6 ± 10.3	0.25
Peak vGRF (N)	1347 ± 403	1083 ± 321	*< 0.01*

Values are presented as mean ± SD; IC, initial contact; vGRF, vertical ground reaction force. * Positive value referring to valgus, negative value referring to varus alignment.

TABLE 12 Hazard ratios with 95% CIs for six biomechanical variables.

		Adjustment factors						
Model	Risk factor	Age	Height (cm)	Weight (kg)	Dominant leg	Sport	Previous ACL injury	League level
1. Knee valgus at IC (°)	1.79[a] (0.71 – 4.55)	1.08 (0.77 – 1.51)	0.87 (0.76 – 0.98)	1.07 (0.98 – 1.17)	Yes 0.69 (0.24 – 1.95) No 1	Floorball 0.48 (0.03 – 7.19) Basketball 1	1.50 (0.27 – 8.20)	4.26 (0.98 – 18.56)
2. Peak knee abduction moment (Nm)	1.12[a] (0.91 – 1.39)	1.11 (0.79 – 1.56)	0.86 (0.76 – 0.97)	1.07 (0.98 – 1.17)	Yes 0.63 (0.22 – 1.84) No 1	Floorball 0.40 (0.03 – 5.71) Basketball 1	1.46 (0.27 – 7.94)	4.43 (1.02 – 19.25)
3. Medial knee displacement (mm)	0.99[a] (0.75 – 1.30)	1.10 (0.80 – 1.52)	0.86 (0.76 – 0.98)	1.07 (0.99 – 1.17)	Yes 0.68 (0.24 – 1.94) No 1	Floorball 0.38 (0.03 – 5.30) Basketball 1	1.45 (0.26 – 8.04)	4.76 (1.11 – 20.46)
4. Knee flexion at IC (°)	1.12[a] (0.63 – 2.00)	1.09 (0.80 – 1.51)	0.86 (0.76 – 0.97)	1.08 (0.99 – 1.17)	Yes 0.67 (0.23 – 1.91) No 1	Floorball 0.40 (0.03 – 5.66) Basketball 1	1.54 (0.28 – 8.53)	4.42 (1.01 – 19.41)
5. Peak knee flexion (°)	0.55[a] (0.34 – 0.88)	1.13 (0.81 – 1.57)	0.83 (0.73 – 0.94)	1.08 (0.99 – 1.17)	Yes 0.59 (0.21 – 1.69) No 1	Floorball 0.39 (0.03 – 5.76) Basketball 1	2.26 (0.35 – 14.75)	5.71 (1.35 – 24.22)
6. Peak vGRF (N)	1.26[b] (1.09 – 1.45)	1.16 (0.82 – 1.63)	0.86 (0.75 – 0.98)	1.02 (0.93 – 1.13)	Yes 0.45 (0.14 – 1.38) No 1	Floorball 0.42 (0.03 – 6.32) Basketball 1	1.79 (0.30 – 10.75)	4.24 (1.04 – 17.34)

[a]Hazard Ratio for 10 unit change; [b]Hazard Ratio for 100 unit change.

IC, initial contact; vGRF, vertical ground reaction force; ACL, anterior cruciate ligament.

The Cox regression models (Table 12) revealed that of the selected biomechanical jump-landing variables, peak knee flexion angle and peak vertical GRF were significantly associated with new ACL injuries. High peak knee flexion angle decreased the risk of ACL injuries (HR for each 10° increase in knee flexion angle: 0.55; 95% CI 0.34 to 0.88; $P = 0.01$), whereas high vertical GRF was associated with increased risk of ACL injury (HR for each 100 N increase in vertical GRF: 1.26; 95% CI 1.09 to 1.45; $P < 0.01$). No statistically significant associations were found for knee valgus angle at IC (HR for each 10° increase in knee valgus angle: 1.79; 95% CI 0.71 to 4.55; $P = 0.22$), knee flexion angle at IC (HR for each 10° increase in knee flexion angle: 1.12; 95% CI 0.63 to 2.00; $P = 0.70$), peak knee abduction moment (HR for each 10 Nm increase in knee abduction moment: 1.12; 95% CI 0.91 to 1.39; $P = 0.27$) or medial knee displacement (HR for each 10 mm increase in medial knee displacement: 0.99; 95% CI 0.75 to 1.30; $P = 0.94$).

Of the adjustment factors included in the regression models, lower height was a significant risk factor in all six models, and playing in at adult league level in five of the six models. Player's age, weight, dominant leg, sport and previous ACL injury were not significantly associated with new ACL injuries (Table 12). In addition, replacing height and weight with BMI was tested, but not included in the final models. BMI did not influence the results, and BMI had no significant association with injuries.

5.4.3 VDJ screening test characteristics

An analysis of receiver operating characteristic (ROC) curve was made for the two significant factors. For peak knee flexion, the ROC showed an area under the curve of 0.6 (indicating a failed-to-poor combined sensitivity and specificity of the test), and for vertical GRF an area under the curve of 0.7 (indicating a fair combined sensitivity and specificity of the test). Figures 19 and 20 illustrate substantial overlap in the frequency distribution between injured and uninjured players for both variables.

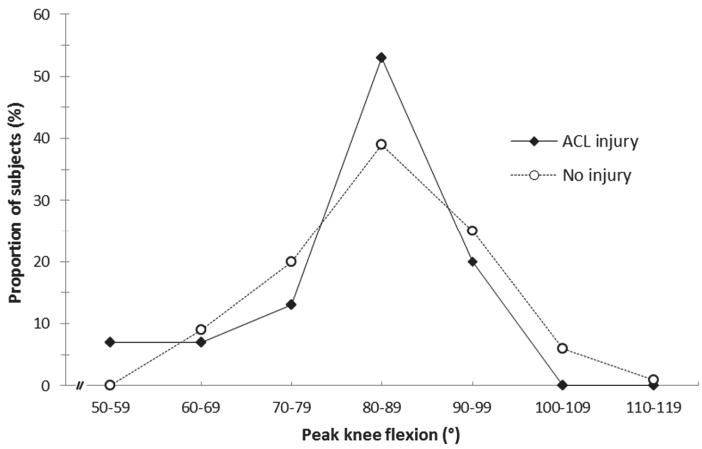

FIGURE 19 Frequency distribution of peak knee flexion for players with and without a new ACL injury.

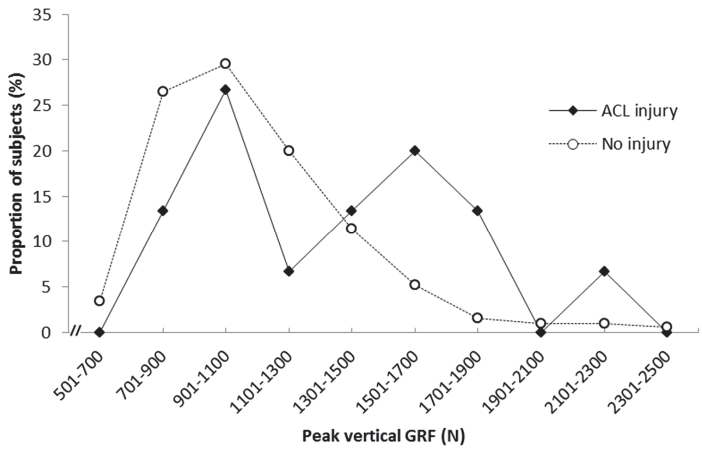

FIGURE 20 Frequency distribution of peak vertical ground reaction force (GRF) for players with and without a new ACL injury.

5.5 Results summary

This study investigated the effectiveness of interventions to prevent sports injuries, the incidence and severity of injuries, and the risk factors for future injuries in youth team sports. The following results were found:

1. The systematic review included 68 RCTs examining the effects of various preventive interventions on the risk of sports injuries. Meta-analyses were conducted using 60 RCTs with 66 comparisons. According to the data available,

training programs with different components appear to be effective in reducing the risk of sports injuries. Other methods, the effectiveness of which has been shown by RCTs, include insoles and external joint supports, whereas stretching, modified shoes, and injury prevention videos failed to show preventive effects.

2. The retrospective analysis on the players' injury history revealed that 39% of the basketball players and 37% of the floorball players reported having had at least one overuse injury during the preceding 12-month period. Overuse injuries caused long absences from full participation in training and playing in both sports. Most of the overuse injuries in these sports affected the lower extremities, with the knee and the lower back being the most commonly injured body sites.

3. The baseline investigation on players' knee control and jump-landing technique revealed that nearly half of the young players had difficulties maintaining good frontal plane knee control during the jump-landing task. Decreased knee control was especially common among female players. Basketball players exhibited larger peak knee valgus angles, and landed with a decreased peak knee flexion angle compared with the floorball players.

4. The prospective risk factor analysis on jump-landing biomechanics showed that stiff landings, with less knee flexion angle and greater vertical ground reaction force, were associated with an increased risk of ACL injury in young female basketball and floorball players.

6 DISCUSSION

6.1 Comparison to previous reviews and meta-analyses

In 2007, Aaltonen et al. (2007) published a systematic review on randomized controlled intervention trials designed to prevent injuries. Since then, the number of RCTs assessing the effects of training intervention on sports injury prevention has increased nearly threefold. Unlike most of the extrinsic risk factors (e.g. environment, playing surface or other players), some of the intrinsic risk factors such as neuromuscular control and muscle strength are modifiable. Training interventions are designed to influence these factors by enhancing athletes' physical and motor abilities. Physical training usually affects many body systems (e.g. cardiovascular-, neuromuscular- and musculoskeletal systems), and training interventions often use a variety of physical and motor fitness components. Thus, interpreting the results of training interventions can be a complex process. For research purposes, there is a desire to identify the most valuable components of an effective intervention.

An earlier systematic review suggested that balance board training is an effective prevention strategy to reduce sports injuries (Aaltonen et al. 2007). The current review and meta-analysis added seven new RCTs investigating balance board training alone or as a part of a multi-intervention, and further supported the beneficial effects of balance board training especially in preventing ankle injuries. The effectiveness of balance training is based on the improved static and dynamic balance and postural control during sporting activities (Emery et al. 2005). As a part of neuromuscular training, balance board training might be effective in reducing other lower extremity injuries as well, although the actual effect of balance board training is then not known. One interesting finding was that 80% of all effective training interventions included balance-enhancing components (Appendix III), which highlights the importance of this training type. In addition, of the five trials using home-based balance training, four appeared to be effective. This confirms that, at least among motivated athletes, home-based training can be as effective as supervised training.

Many have merged preventive training into warm-up procedures, but the effectiveness of these actions has varied (Fradkin, Gabbe & Cameron 2006). In the current investigation, the pooled result of different warm-up programs showed a preventive effect, but still, half of the studies failed to achieve significant results. The lack of significant effects in some individual studies was presumably affected by poor compliance (Steffen et al. 2008) and the small number of events (Waldén et al. 2012). Most of the warm-up programs included a wide spectrum of different types of exercises (e.g. balance, strength, plyometrics) intended to enhance neuromuscular control. Thus, it is not known which exercises are the most beneficial components of a preventive intervention. Furthermore, most of the warm-up programs were conducted among soccer players and more studies are needed to investigate their effectiveness among other sports populations.

When dividing training interventions into subgroups, some overlap in the contents of the training programs used in each group was inevitable. A neuromuscular training method was therefore included in many subgroups. Neuromuscular training is suggested to have beneficial effects on sense of joint position, stability, and reflexes, which may affect the risk of being injured (Eils et al. 2010, Herman et al. 2012, Hubscher et al. 2010). Another benefit of neuromuscular training is that it can be implemented effectively with no additional equipment (Herman et al. 2012), thereby offering a cost-effective way to reduce sports injuries.

The findings from two high-quality trials (Askling, Karlsson & Thorstensson 2003, Petersen et al. 2011) on the effectiveness of eccentric strength training to reduce the risk of hamstring injuries among football players are consistent with previous systematic review (Hibbert et al. 2008). Two small strength-training trials, however, failed to show a preventive effect (Gabbe, Branson & Bennell 2006, Mohammadi 2007). Interventions aimed at enhancing strength and power features have not yet been widely studied in RCTs. Instead, strength and power components have been successfully used as a part of multi-interventions; nearly half of the effective training interventions in the current meta-analysis included strength or power training components (Appendix III).

When most of the training interventions combine various components of physical and motor training, it is almost impossible to identify the actual effective components and also the parts having no influence on injury risk. The preventive effect of a training program is likely the sum of individual effective exercises or could also be a result of the interaction of different components. Nevertheless, implementation of an effective training program requires a thorough understanding of injury mechanisms and risk factors, and carefully planned exercises that are adjusted to the injury problem within the target population at hand. Another major issue concerning the effectiveness of any intervention is compliance to the intervention. Given that high compliance can further increase the effectiveness of a preventive training program (Steffen et al. 2013), it is essential to motivate athletes and their coaches to follow the program.

While training interventions comprise a large group of trials, other interventions, including equipment interventions, have not been extensively studied in RCTs. Orthotic or shock-absorbing insoles are suggested to prevent lower limb injuries (Collins et al. 2007) and tibial stress fractures (Hume et al. 2008, Rome, Handoll & Ashford 2005). Although the pooled result in the current meta-analysis supported the use of insoles to prevent lower limb injuries, two studies (Mattila et al. 2011, Withnall, Eastaugh & Freemantle 2006) found no preventive effects. The quality assessment of these trials revealed that only the two trials with non-effective interventions were rated as having a low risk of bias, whereas the other trials had a high risk of bias. Therefore, the beneficial effect of insoles on injury risk should be taken with caution.

Studies on external joint supports showed very low statistical heterogeneity, and all trials except one demonstrated a beneficial effect against ankle, knee or wrist injuries. Ankle sprains are often reported as the most common injury type in sports (Dizon & Reyes 2010, Verhagen et al. 2004). The present finding of the effectiveness of external ankle supports is in line with previous studies (Dizon & Reyes 2010, Verhagen et al. 2004). A preventive effect was found for both first-time (McGuine, Brooks & Hetzel 2011, McGuine et al. 2012, Sitler et al. 1994) as well as recurrent (McGuine, Brooks & Hetzel 2011, McGuine et al. 2012, Mohammadi 2007, Surve et al. 1994, Tropp, Askling & Gillquist 1985) ankle sprains. Only one study (Sitler et al. 1990) investigated the effects of knee bracing on knee injury risk, and reported a preventive effect. However, the preventive effect was found only in defensive players, and based on a single study, conclusions on the effectiveness of knee bracing cannot be drawn. Furthermore, considering the promising findings from training interventions, it can be hypothesized that interventions based on physical training rather than external joint supports might be more effective in reducing the risk of knee injuries.

Other methods, such as stretching, protective head equipment, modified shoes and informative videos, have been studied less in RCTs, therefore drawing conclusions about their effectiveness is not reasonable. Furthermore, some interventions, such as rules and regulations (Black et al. 2016, Macan, Bundalo-Vrbanac & Romic 2006), development of safer equipment (Stevens et al. 2006) and environment (for example ice-hockey arenas with flexible boards and glass) (Tuominen et al. 2015), and the use of protective headgear in high-risk sports (Hollis et al. 2009), cannot be studied in randomized controlled settings, but can also have an influence on the risk of injuries.

Looking at the evidence published after meta-analysis reveals that at least three RCTs support the current results on the effectiveness of training interventions. Silvers-Granelli et al. (2015) studied the FIFA 11+ warm-up program and adds to the current evidence on its effectiveness in reducing injuries among competitive male collegiate soccer players as well. A study by van der Horst et al. (2015) endorses the effectiveness of eccentric strength training (by Nordic hamstring exercise) in the prevention of hamstring injuries. Another study provides important knowledge on the effectiveness of exercise program to prevent overuse shoulder injuries in throwing sports (Andersson et al. 2016). In addition, RCTs with no preventive effect have been published since the meta-analysis. Interestingly, the FIFA 11+ program did not reduce overall injury incidence among senior soccer players (Hammes et al. 2015). However, the program did reduce severe injuries, and the authors concluded that the lack of preventive effect was due to the low frequency of training sessions. According to one pilot study, strength training had no effect on running-related injuries in novice runners (Baltich et al. 2016). Studies on running shoes have shown that motion control shoes reduce injuries in those with a pronated foot type (Malisoux et al. 2016a), whereas low-drop running shoes failed to reduce injuries (Malisoux et al. 2016b).

Prevention of injuries among adolescent, non-elite athletes should be a special target. Much of the important work among adolescents is done by untrained coaches (such as parents, former athletes, etc.), without the possibility of using team physiotherapists or physicians. Thus, it is essential that time and resource-efficient preventive methods are studied and implemented. Sports-specific preventive training programs should be developed and tested among adolescent athletes as well. Although many effective training interventions to reduce the risk of acute injuries exist, interventions aimed at prevention of overuse injuries are still scarce. Furthermore, wide-scale implementation studies are needed to find out how interventions proven to be effective in smaller controlled study settings work in real life.

6.2 Overuse injuries in young athletes

Research from the last 30 years has shown that musculoskeletal discomfort, such as Osgood-Schlatter's disease and low back pain, are more common among physically active adolescents than their non-active counterparts (Kujala, Kvist & Heinonen 1985, Kujala et al. 1996, Kujala, Taimela & Viljanen 1999). It has been speculated that high training volume and competition load increase the risk of overuse injuries in team sports. To date, however, epidemiological studies on overuse injuries in youth team sports have been scarce, and few studies on the prevalence of overuse injuries exist among adult populations. In floorball, overuse injuries cover approximately 17–30% of all injuries (Pasanen et al. 2008a, Snellman et al. 2001, Wikström & Andersson 1997). Overuse injury proportion in the current youth floorball population (30%) was similar to these, although not as high (40%) as reported most recently among Swedish elite players (Tranaeus, Götesson & Werner 2016). Similar numbers have also been reported in basketball studies, where overuse conditions account for 15–27% of all injuries among professional players (Deitch et al. 2006, Drakos et al. 2010, Starkey 2000). In the current study, 31% of all injuries in basketball players were overuse injuries.

When inspecting injury incidences, the incidence of 1.0 injuries/1,000 hours of exposure observed in both sports is considerably lower than the incidence reported by Cumps et al. (2007) in senior basketball players. Although comparing these rates is not possible due to different study designs and methods, it is interesting that Cumps et al. (2007) used an injury definition based on physical discomfort rather than time-loss from participation. It has been shown that standard injury surveillance methods based on time-loss often underreport overuse injuries because athletes tend to train and compete despite the symptoms (Clarsen, Myklebust & Bahr 2013). Thus, it is possible that the injury definition used in the current study underestimates the true incidence of overuse injuries, and that young team sport players actually suffer more overuse injuries than the current results show. Interestingly, the players in the present analysis reported a total of 150 overuse conditions that caused no time-loss and hence were not included in the final analysis. Including these conditions in the present analysis would give overuse injury incidence of 1.8/1,000 hours of exposure.

The current findings that most of the overuse injuries in both basketball and floorball affect the lower extremities – with the knee being the most commonly injured site – are in line with previous studies on adult players (Cumps, Verhagen & Meeusen 2007, Pasanen et al. 2008a). In basketball, which includes repetitive jump-landings, a high prevalence of patellofemoral pain (PFP) has been reported (Cumps, Verhagen & Meeusen 2007, Deitch et al. 2006, Drakos et al. 2010, McCarthy et al. 2013, Starkey 2000). Although high training load is the most commonly reported risk factor for patellar tendinopathy (Cumps, Verhagen & Meeusen 2007, van der Worp et al. 2012, Visnes & Bahr 2013), overuse knee injuries are presumably multi-factorial injuries (van der Worp et al. 2014). There is some evidence that in sports involving jumping and landing, the landing biomechanics associated with PFP are partly similar to factors associated with ACL injuries. These include increased valgus loading during landing and landing with less knee flexion (Weiss & Whatman 2015). In addition to landing biomechanics, it has been suggested that anatomical factors, such as a smaller tendon cross-sectional area, might also predispose for patellar tendinopathy (Couppé et al. 2013). During growth spurts, young athletes develop their muscle strength rapidly, whereas tendons do not reach their stiffness at a similar speed, making the tendons of a young athlete vulnerable to physical loading (Mersmann et al. 2014). Tendineal problems, such as Osgood Schlatter's disease and non-specified pain in the tendon insertions, are common among young athletes participating in sports involving repetitious impact movements including jump-landings and sudden stops (Kujala, Kvist & Heinonen 1985). Although a young athlete's overuse knee conditions are often self-limiting, they are long-lasting (Kujala, Kvist & Österman 1986). In the present study also, knee injuries were the most common cause of long time-losses.

Unlike for basketball players, who sustained most often knee overuse injuries, the most commonly injured body site in junior floorball players was the lower back area, and the male players suffered significantly more lower back overuse injuries compared with females. These results are in line with a recent investigation of elite floorball players (Tranaeus, Götesson & Werner 2016). Low back pain is a common problem in many sports involving repetitious or continuous back extensions, flexions, or rotations, and high impacts (Stuber et al. 2014, Trainor & Trainor 2004, van Hilst et al. 2015). Floorball is played in a low position, which causes strain to the lower back, especially if the core muscles are weak and the back is forced to support the position.

Recently, hip and groin pain among adolescent athletes has received an increasing amount of attention (Rankin, Bleakley & Cullen 2015). Hip joint pathology, such as femoroacetabular impingement (FAI), is a common reason behind hip and groin pain (Khanna et al. 2014, Nepple, Vigdorchik & Clohisy 2015, Rankin, Bleakley & Cullen 2015). Participation in high-level team sports (such as basketball, ice hockey, and football) during skeletal maturation is associated with increased risk of femoral head-neck deformity (Siebenrock et al. 2011, Siebenrock et al. 2013, Tak et al. 2015). This cam-type deformity is a condition where femoral head loses its normal sphericity, and may lead to FAI (Siebenrock et al. 2013). Especially adolescent male athletes participating in sports requiring repetitive high-impacts, hip flexion and internal rotation are at increased risk of cam deformity (Agricola et al. 2012, Agricola et al. 2014, de Silva et al. 2016). In the current study, hip and groin overuse injuries tended to be more common among male players, although no significant associations with this sample size were detected. Hip and groin overuse symptoms, especially during skeletal maturation, should be taken seriously, because FAI is known to be associated with reduced activity and hip osteoarthritis (de Silva et al. 2016).

Overuse injury profiles seem to vary both by sport and by gender. In the current study, young male floorball players reported more overuse injuries than females. In basketball, no gender differences were observed. Tranaeus et al. (2016) found that most of the injuries in elite male floorball players were actually overuse rather than traumatic injuries. This was not the case for female players, who sustained more traumatic than overuse injuries. Similarly, Wikström et al. (1997) reported overuse injuries in floorball being more common among male players than female players, whereas Snellman et al. (2001) found the opposite result. Patellar tendinopathy is an overuse condition that is far more common among male athletes than it is among female athletes (Lian, Engebretsen & Bahr 2005, Visnes & Bahr 2013, Zwerver, Bredeweg & van den Akker-Scheek 2011). On the other hand, Cumps et al. (2007) found female players to have a higher risk for all knee overuse injuries, especially patellofemoral pain. Possible explanations for the gender differences might be differences in training volume (Visnes & Bahr 2013), and also higher muscle strength and jumping capacity in males (Zwerver, Bredeweg & van den Akker-Scheek 2011).

Recording overuse injuries in sports injury research has been methodologically challenging. It has been suggested that previous epidemiological studies have found only a tip-of-the-iceberg of the true overuse injury burden (Clarsen et al. 2015), and that overuse injuries in fact is a larger problem than expected (Bahr 2009, Clarsen, Myklebust & Bahr 2013). Current recommendations for recording overuse injuries are based on detecting symptoms (such as pain and discomfort) that affects sports performance (Clarsen, Myklebust & Bahr 2013). Pain symptoms in overuse injuries typically fluctuate and cause no time-loss from training or competition (Bahr 2009, Clarsen, Myklebust & Bahr 2013). With this being said, it is worth mentioning that overuse injuries in the current investigation, although using time-loss definition, caused relatively long absence from sports participation, and the true influence might be even bigger.

6.3 Movement control deficits and the risk of injuries

Previous investigations have shown that serious injuries in team sports occur during rapid movements, such as landing from a jump or changing direction (Koga et al. 2010, Krosshaug et al. 2007, Olsen et al. 2004). Maintaining good knee alignment during these high-speed sporting tasks has been suggested to provide protection against ligament injuries of the knee (Hewett et al. 2005a). Movement control in the current study was measured by using a vertical drop jump task, which is a functional test designed to screen an athlete's ability to maintain good knee alignment in an impact.

The baseline investigation on players' knee control and jump-landing technique has yielded two important findings. First, nearly 80% of female athletes exhibited decreased frontal plane knee control, whereas decreased control was observed in only 20% of male players. This finding that poor knee control is especially common among female athletes is in line with earlier studies (Chappell et al. 2002, Ford, Myer & Hewett 2003, Kernozek et al. 2005, Malinzak et al. 2001), and highlights the need for neuromuscular training to enhance knee control in order to decrease the risk of future injuries. The second important finding was the difference found between basketball and floorball players. Floorball is a ballgame which includes frequent accelerations and decelerations as well as running with rapid turns, but involves less jumping and rebounding movements. It was hypothesized that basketball players would benefit from jump and rebound practice and thus would perform better in the jump-landing task. Contrary to this expectation, the basketball players actually landed with greater knee valgus movement and with less knee flexion than the floorball players did. Based on this finding, it seems plausible that the ability to control the knee during a jump-landing is not developed simply by playing a sport that involves frequent jumping movements. Instead, more focused training to improve knee control is needed.

In order to determine if true associations exist between the decreased knee control in female athletes and future ACL injuries, prospective risk factor analysis was needed. Some differences in the outcomes of interest and subject characteristics exist in the current study compared with other risk factor studies available. In their analysis, Hewett et al. (2005a) measured multiple variables, including hip joint motions. Similar to Krosshaug et al. (2016), the current study selected only a limited number of potential risk factors. The outcomes were chosen based on the current literature on the factors suggested to be associated with ACL injuries. The participants in the current study were younger (15 years on average) and presumably less trained than the elite adult cohort of Krosshaug et al. (2016), and more similar to that of Hewett et al. (2005a). Although most of the participants in the current study played in junior leagues only, there were some talented players (*n* = 23) who participated in adult league matches as well. Interestingly, these players turned out to be at increased risk of ACL injuries, probably because of a high total training and match load and higher physical demands on adult level.

Somewhat surprisingly, the results of the study found no significant association between independent measures of knee valgus loading and future ACL injuries. Instead, landing with decreased knee flexion and increased vertical ground reaction force were found to be significant risk factors for future ACL injuries in young female basketball and floorball players. The next chapters aim to provide rationale for these findings.

6.3.1 Knee valgus loading and ACL injury risk

Knee valgus movement has been identified as an important component in the noncontact ACL injury mechanism (Koga et al. 2010, Koga et al. 2011, Krosshaug et al. 2007, Olsen et al. 2004, Waldén et al. 2015). Olsen et al. (2004) suggested that the ACL injury mechanism could be a combination of a rotation (external or internal) of the tibia and a forceful quadriceps contraction when the knee is in a valgus position. This leads to impingement of the ACL on the femoral condyle, which causes the ligament rupture (Ebstrup & Bojsen-Møller 2000). Similarly, Koga et al. (2010) stated that valgus loading is probably a contributing factor to ACL rupture, but valgus motion exists together with internal tibial rotation. Furthermore, Koga et al. (2011), in their other investigation using a model-based image-matching technique also observed significant anterior tibial translation, and concluded that these three motions (valgus, rotation, and anterior tibial translation caused by sagittal plane loading) are presumably critical components of the ACL injury mechanism.

Although valgus movement is present in most injury situations, the association between knee valgus loading and future ACL injury risk has been shown in only one prospective study (Hewett et al. 2005a). Hewett et al. (2005a) used the VDJ test to identify risk factors for ACL injuries in female athletes and found that knee valgus angles (IC and peak values) were associated with future ACL injury. More recently, Krosshaug et al. (2016) conducted a comparable investigation in a larger population of female elite athletes, and found that only medial knee displacement was significantly associated with ACL injuries. Although the current study showed a similar trend with IC valgus angle, neither of the variables measuring knee valgus motion or loading reached statistical significance. In order to determine if knee valgus or abduction moment in combination with knee flexion and/or vertical GRF would have significant interaction effects, additional analyses were conducted, and no significant associations with injury risk were found. Due to limitations in statistical power, these results should be interpreted with caution. Two other risk factor studies available used a different approach by analyzing the LESS scores during the VDJ, but no associations with valgus loading and ACL injuries were reported (Padua et al. 2015, Smith et al. 2012).

Even though the current investigation found no independent association between knee valgus and ACL injury risk, knee valgus movement has to be seen as an undesirable movement control deficiency. Furthermore, most of the sporting movements occur in all three planes of motion, and these motions are linked to each other. It has been demonstrated that athletes landing with decreased knee and hip flexion exhibit increased knee valgus movement compared to those landing with more flexed position (Pollard, Sigward & Powers 2010). Unpublished preliminary analysis of the current data yielded similar findings: the stiff landing group demonstrated higher valgus and abduction moments compared with the soft landing group. During stiff landings, the energy of the impact is being absorbed by the joints and ligaments instead of the muscles. This so-called ligament dominance leads to increased knee valgus movement (Hewett et al. 2010). Deficiencies in hip strength and trunk control have been associated with both increased knee valgus movement (Claiborne et al. 2006, Hollman et al. 2009, Willson, Ireland & Davis 2006) and knee injury risk (Khayambashi et al. 2016, Zazulak et al. 2007). Thus, it is very important for young athletes to achieve adequate strength levels in the lower extremities, hip, and core in particular.

In addition to its main function as a primary restraint of anterior tibial translation, ACL also prevents rotations of the tibia and valgus angulation (Duthon et al. 2006, Markatos et al. 2013, Petersen & Zantop 2007). Cadaver investigations have shown that sectioning of the ligament results in significant valgus and varus instability in low knee flexion angles (Olsen et al. 2004). This has raised a discussion on whether the consistent knee valgus found in biomechanical investigations is the actual cause or rather a consequence of the injury (Olsen et al. 2004, Stuelcken et al. 2015, Waldén et al. 2015). Some have further hypothesized that valgus collapse is so common among females due to lower movement resistance after the injury (e.g. due to lower muscle strength and higher joint laxity) (Waldén et al. 2015). External knee rotation is also often described as a part of the injury mechanism, although there is evidence that external rotation could be occurring after an ACL rupture (Meyer & Haut 2008). Loading studies have not been able to show that knee valgus moment and internal/external rotation moments can independently produce ACL injuries without the presence of high sagittal plane forces (Yu & Garrett 2007). Forceful contraction of the quadriceps muscles can, on the other hand, cause a rupture of the ACL without the presence of valgus loading (DeMorat et al. 2004).

6.3.2 Sagittal plane loading and ACL injury risk

Many studies have demonstrated that sagittal factors (e.g. high ground reaction force, great quadriceps muscle contraction force, and small knee flexion angle) contribute to ACL injury (Chappell et al. 2002, Chappell et al. 2005, Koga et al. 2010, Meyer & Haut 2008, Olsen et al. 2004). However, the association between the sagittal factors and the risk of ACL injury has not been established in prospective studies earlier. One study reported lower peak knee flexion angles and higher vertical GRF in ACL injured vs. uninjured females, but these factors were not significant in the regression analysis (Hewett et al. 2005a). The justification for the current findings can be found from ACL loading and injury mechanism studies.

The effects of sagittal plane knee motion on loading of the ACL have been studied in many investigations both in vitro (Berns, Hull & Patterson 1992, DeMorat et al. 2004, Markolf et al. 1990, Markolf et al. 1995, Withrow et al. 2006) and in vivo (Beynnon et al. 1995, Beynnon & Fleming 1998). Berns et al. (1992) studied the effects of both pure and combined loading on ACL strain in cadaver knees. The loading forces were applied in 0, 15 and 30 degrees of knee flexion. The results of this study showed that the anterior medial bundle of the ACL was primarily strained by anterior tibial shear force. Neither pure internal/external rotation moment nor varus/valgus moment increased the ACL strain at any of the flexion angles. However, both valgus moment and internal moment applied in combination with anterior shear force generated higher strain on the ACL compared with anterior shear force alone. Similarly, Markolf et al. (1995) in their cadaver study found anterior tibial shear force to be the most direct loading mechanism of the ACL. They reported recording the highest loading forces when combining anterior tibial shear force and internal tibial rotation torque when the knee was at full extension. Also in this study, combined anterior tibial force and valgus moment generated higher ACL loading than anterior shear force alone. In addition, Fleming et al. (2001) studied the effect of weightbearing and external loading on ACL strain in vivo and found that ACL strain increased when the anterior shear force increased and the internal rotation moment increased, while valgus/varus and external rotation moments had little effect on ACL strain under weightbearing conditions. Collectively, these studies outline a critical role of anterior shear force as a major determinant to ACL loading (Yu & Garrett 2007).

Anterior tibial shear force at the proximal end of the tibia pulls the tibia anteriorly in relation to the femur, causing strain to the ACL. Beynnon et al. (1995) studied ACL ligament strain during different muscle activities in vivo, and found that isometric quadriceps contraction at 15 and 30 degrees of knee flexion generated a significant ligament strain. Similar increases in ligament strains were not observed in knee angles of 60 and 90 degrees or any flexion angle during isometric hamstring contraction. DeMorat et al. (2004) conducted an experimental trial where they induced aggressive physiologic quadriceps contraction to cadaver knees, with the knees positioned in 20 degrees of flexion.

Quadriceps loading produced anterior displacement of the tibia an average of 19 mm causing an injury to the ACL, whereas only slight changes were observed in knee valgus (average 2.3 degrees) and internal rotation (average 5.5 degrees). A similar sagittal plane loading mechanism was found by Kim et al. (2015) who determined knee kinematics during ACL injuries based on bone bruise location. They reported only a slight valgus rotation, whereas a large tibial translation and a large internal rotation when the knee was near extension were observed.

The above mentioned studies show that the quadriceps have a major role in the injury mechanism as a producer of intrinsic force, and forceful quadriceps contraction when the knee is near full extension can lead to significant ACL strain (Beynnon et al. 1995, Beynnon & Fleming 1998, Markolf et al. 1995) or even be a cause of the ACL rupture (DeMorat et al. 2004). The hamstrings contraction when the knee is flexed produces larger posterior tibial shear force which unlike anterior shear force protects the ACL (Kernozek et al. 2013). Female athletes have a tendency to use the quadriceps muscles over the hamstring muscles in order to stabilize the knee joint (Hewett et al. 1996, Huston & Wojtys 1996). This quadriceps dominance leads to increased stress to the ACL. Better activation of the hamstrings could increase the knee flexion during landing and absorb the force through muscles instead of ligaments (Hewett et al. 2010).

Jump-landings with less knee flexion (i.e. stiff landing) produce higher vertical ground reaction forces (DeVita & Skelly 1992, Laughlin et al. 2011, Myers et al. 2011) and knee extension moments (Myers et al. 2011), and are suggested to cause a greater stress on the ACL compared with a softer landing strategy (Laughlin et al. 2011, Myers et al. 2011). According to a study by Weinhandl et al. (2013), ACL loading increased when a sidestep cutting task was performed without preplanning and the increase was primarily due to an increase in sagittal plane loading. However, Myers et al. (2011) did not find a difference in anterior tibial translation, knee rotation or valgus movement during stiff landing compared with soft landings in healthy individuals under testing conditions. The findings from the current study support the evidence that sagittal plane loading factors have an important role in determining ACL loading, and that a softer landing strategy may decrease the loading and affect the risk of being injured.

6.3.3 Movement control screening

In order to target preventive training more effectively, injury risk factors need to be thoroughly determined and the athletes at risk need to be identified through accurate movement control screening tests. The purpose of screening is to detect athletes at risk before the injury occurs, thus enabling early intervention in the hope of preventing injury. In order to validate a screening test, there needs to be a strong relationship between the test measure and injury risk, and the test needs to predict injuries with adequate test properties (Bahr 2016).

The current study showed a significant relationship between stiff landings and ACL injury risk. However, as the VDJ test performance was measured on a continuous scale, substantial overlap between injured and uninjured players for both peak knee flexion and vertical GRF was observed. The ROC analysis revealed an area under the curve of only 0.7 for vertical GRF and 0.6 for peak knee flexion, clearly demonstrating that these measures cannot be used as screening tests to predict ACL injuries. Similar findings were reported by Krosshaug et al. (2016), who concluded that the VDJ test is a poor screening test for predicting ACL injuries in elite female athletes.

6.4 Practical implications

Although prevention of acute lower extremity injuries has been the main target in intervention studies, overuse injuries can also be decreased through training interventions (Andersson et al. 2016, Lauersen, Bertelsen & Andersen 2014). Most of the effective training interventions studied in RCTs include exercises from balance/coordination training and strength training (Appendix III). Furthermore, strength training is effective in reducing hamstring muscle injuries, and recent studies have also shown promising results for strengthening exercises in preventing shoulder injuries (Andersson et al. 2016, Osteras, Sommervold & Skjolberg 2015). Adequate strength levels, especially in the lower extremities, hip and core, are needed in high-speed team sports to ensure good movement control. Appropriately designed and supervised resistance training as part of a neuromuscular training program is safe and supported for adolescent athletes as well (Lloyd et al. 2014).

Several investigations have outlined the importance of enhancing knee control especially in young female athletes participating in pivoting and jumping sports (Chappell et al. 2002, Ford, Myer & Hewett 2003, Holden, Boreham & Delahunt 2015, Kernozek et al. 2005). Decreasing knee valgus loading and increasing knee flexion during landing and cutting movements seems to be important for avoiding both acute and overuse knee injuries (Boling et al. 2009, Hewett et al. 2005a, Myer et al. 2010, Weiss & Whatman 2015). Lower limb alignment during functional tasks can be improved through specific neuromuscular training (Noyes et al. 2005, Noyes et al. 2012), which is also effective in reducing the risk of ACL injuries in young female athletes (Yoo et al. 2010a). Neuromuscular training can increase pre-activation of the hamstring muscles during high-speed movements (Zebis et al. 2008), which can reduce the quadriceps draw force and further decrease ACL loading. Hip strengthening exercises are effective in improving the quality of jump-landing by both increasing knee flexion as well as decreasing knee valgus movement during jump-landing (Stearns & Powers 2014).

Neuromuscular imbalances as well as errors in jump-landing and cutting techniques should be avoided and corrected not only to decrease the risk of injuries but also to optimize the biomechanics of athletic movements (Boling et al. 2009, Ford, Myer & Hewett 2003). It is motivating for athletes and coaches to know that injury prevention programs can improve sports performance, and are especially beneficial for young females, who usually have a lower level of strength and power compared with young male athletes (Hewett, Ford & Myer 2006).

The popularity of the double-leg jump-landing test in both injury research and practice arises from the study by Hewett et al. (2005a). Analysis on injury situations have shown that ACL injuries typically occur in single-leg activities such as landing on one leg or side-step cutting (Krosshaug et al. 2007, Olsen et al. 2004, Waldén et al. 2015), yet the data available on biomechanical risk factors for ACL injuries arises from double-leg jump-landing tasks. Kristianslund & Krosshaug (2013) showed that athletes demonstrate different knee kinematics and kinetics in sport-specific cutting tasks compared with drop-jumps. The current study highlights the importance of the assessment of landing stiffness during the VDJ test. However, it has to be acknowledged that this is the second study showing that the double-leg drop jump test has limited value in predicting ACL injuries. Studies investigating non-specific knee injuries have suggested that other measures, such as knee separation during a double-leg drop jump (O'Kane et al. 2016) or the combination of knee valgus and lateral trunk motion during a single-leg drop jump (Dingenen et al. 2015) may be potential screening tools. In an environment where the athlete is less aware of being monitored, athletes might exhibit less controlled and more natural movements. Thus, risk factors in future studies should perhaps be analyzed in more sport-specific movements as well as include the effects of anticipation on the test (Meinerz et al. 2015, Weinhandl et al. 2013).

6.5 Strengths and limitations

This study provides important insights into the epidemiology of overuse injuries, movement control deficits and injury risk factors in young team sports athletes as well as into injury prevention through randomized controlled trials. The two key strengths of the current dissertation are the risk factor analysis (Study IV) and the comprehensive meta-analysis on published RCTs (Study I). These investigations, in particular, provide high-quality evidence of what has an impact on young athletes' health. Based on these results, it is possible to summarize what methods are effective and which are ineffective in reducing the risk of injuries, as well as what methods need to be studied further. Additionally, the large sample size and the high response rate to the injury questionnaire, the low drop-out rate, the accuracy of the 3D motion analysis method utilized, and the prospective follow-up for injuries and individual player exposures contribute to the value of this study. Nevertheless, there are some limitations that need to be addressed.

The quality assessment in the meta-analysis revealed various methodological weaknesses in the included trials. According to the current guidelines (Furlan et al. 2009), a low risk of bias is achieved when at least six of the twelve criteria have been met and no serious flaws have been detected. There is a high risk of bias if the score given to a study is less than six or if the study has serious flaws. In the current review, most of the studies (47 trials) were rated as having a high risk of bias, whereas only 21 studies were assessed as having a low risk of bias. The following issues regarding internal validity of the included studies were recognized: (1) a possibility of selection bias because of inadequate concealment of allocation or baseline differences between groups in 64 trials, (2) a possibility of performance bias due to the lack of blinding of participants or care providers, the effect of co-interventions and inadequate compliance in all 68 trials, (3) a possibility of detection bias due to the lack of blinding of outcome assessors or different timing of the outcome assessment in 48 trials, and (4) a possibility of attrition bias due to a lack of intention-to-treat analysis or unacceptable drop-out rate in 44 trials. Given the nature of injury prevention interventions, the blinding of the participants as well as avoiding co-interventions is in most cases very difficult, and it is almost impossible for a study to receive the highest score. Almost all of the 21 studies considered to have a low risk of bias were conducted in the 2000s, suggesting that the quality of injury prevention studies (and study reports) has improved from earlier years.

Most of the participants in the RCTs were young adult athletes, but only a few of the studies included senior athletes or children. The studies involving the use of insoles were conducted exclusively among military recruits, and studies on strength training included only male football players with rather low sample sizes. Consequently, the generalizability of the results to other age and sports groups is limited and the effectiveness of the interventions should be tested more widely in future studies.

The literature search revealed gaps in high-level evidence in certain areas, such as stretching, and rules and regulations. The meta-analysis included only randomized controlled trials. Hence, methods studied in different research settings were not included and their effectiveness cannot be determined based on the current data. The studies included in the meta-analysis were divided into subgroups according to the preventive measures, despite the fact that the interventions were not identical in all respects. Due to this, the study designs and participants in the subgroups were decidedly heterogeneous.

The reliability of the retrospectively collected data in Study II is affected by recall bias and should therefore be interpreted with caution. Unfortunately, it was not possible to collect detailed injury diagnoses by using the questionnaire only. However, the use of injured body parts and the number of injuries only may have minimized the recall bias, because this information is rather easy for the athlete to remember. Furthermore, the questionnaire was completed on the day the player entered the study, which allowed the researcher to check the completed questionnaire with each player. Exposure hours were calculated by using average values reported in the questionnaire for training and playing. Thus, these values are only estimates from the real exposure. Furthermore, the injury definition based on time loss, although emphasizing time loss from full sports participation, might have left aside injuries that caused no time loss or were transient in nature. It is possible that this resulted in an underestimation of the overuse problem in this population.

Although 3D motion analysis has been referred to as the gold standard for assessing lower extremity kinematics and kinetics (McLean et al. 2005, Nilstad et al. 2014a), this method has some limitations. The kinematic calculations in a marker-based motion analysis will be influenced by soft-tissue movement artifacts (Leardini et al. 2005), which affect knee valgus measurements in particular (Miranda et al. 2013, Stagni et al. 2005). Yet a reasonable correlation between valgus angles measured by 3D method and physiotherapist's visual observation has been reported (Nilstad et al. 2014a). Knee flexion, however, as well as ground reaction force measured with two force platforms, is a valid and accurate measure (Stagni et al. 2005). In addition, medial knee displacements and abduction moments will be less affected by the soft tissue artifact because the joint center estimation is much less sensitive to soft tissue artifacts than valgus angle calculation. Another limitation of the marker-based motion analysis is that the analyses are highly dependent upon marker placement (Mok, Kristianslund & Krosshaug 2015). In order to minimize possible errors in marker placement, all marker places were carefully defined and two physiotherapists were trained to place markers uniformly. Each study year, a single physiotherapist was responsible for marker placement on all players.

The risk factor study was conducted with a relatively long follow-up of three years. Still, the prevalence of ACL injuries remained low, thus limiting statistical power of the study. It is possible that risk factors other than strong ones were not detected because of the small number of injury cases (Bahr & Holme 2003). The number of cases (15) in the current study, however, was higher than, for instance, that of Hewett et al. (2005a) (9 cases). Statistical models were calculated separately for each variable to determine independent risk factors. Using a combined model would have required a much higher sample size. Players with a previous ACL injury were not excluded. However, the analyses were also tested with including only players without previous injury and although there were two fewer injured players, the results were similar. In the final models, previous injury was included as an adjustment factor for both legs because the previous injury may affect both the injured and uninjured leg.

This study investigated only a limited number of biomechanical risk factors, and certainly other possible ACL injury risk factors exist. Besides the knee, biomechanics of the trunk, hip and ankle may also be associated with ACL injury risk (Alentorn-Geli et al. 2009, Weiss & Whatman 2015, Zazulak et al. 2007). Limited range of motion in ankle dorsiflexion and hip rotation (Amraee et al. 2015) as well as foot pronation (Alentorn-Geli et al. 2009) may have an influence on knee biomechanics and thus increase the risk of ACL injuries. Strength deficits, especially a decreased hamstring-to-quadriceps strength ratio and core strength as well as muscular fatigue have also been associated with increased injury risk (Alentorn-Geli et al. 2009). Outside the scope of the current study, it has been suggested that anatomical and structural factors such as generalized joint laxity, knee hyperextension, knee joint laxity (Vacek et al. 2016), small intercondylar notch width (Simon et al. 2010, Sturnick et al. 2015), increased lateral tibial plateau slope (Beynnon et al. 2014), increased femoral anteversion (Amraee et al. 2015), and a high quadriceps angle may predispose athletes to ACL injuries (Alentorn-Geli et al. 2009). Furthermore, hormonal factors, such as the pre-ovulatory phase of menstrual cycle, have been associated with ACL injury risk (Alentorn-Geli et al. 2009). Many of the aforementioned factors have been proposed to be more common among female athletes, hence explaining the high incidence of ACL injuries among females. However, the strength of the evidence varies and controversy exists in many suggested risk factors. In addition, there might be other factors, such as genetics, that remain unknown. Although it is important to determine all predisposing factors, the emphasis should be on the investigation of modifiable risk factors, such as biomechanics and neuromuscular control.

7 MAIN FINDINGS AND CONCLUSIONS

In response to the aims of the current study, the main findings and conclusions of the study are as follows:

1. According to the data available, training interventions, insoles, and external joint supports are effective methods for reducing sports-related injuries. Effective training programs commonly included exercises intended to enhance neuromuscular control.

2. Although most of the injuries in basketball and floorball are traumatic injuries, young team sports athletes encounter a considerable amount of overuse injuries that affect the knee and the lower back in particular. Overuse injuries may cause long-term pain and discomfort, making the athlete unable to fully train and compete.

3. Deficient movement control during jump-landings is highly common, especially among young female basketball and floorball players. Basketball players landed with larger knee valgus and with a stiffer landing technique than floorball players did. Proper knee control and jump-landing technique does not seem to develop in young athletes simply by playing the sport, despite the fact that jump-landings occur frequently in practice and games. Specific neuromuscular training is needed to improve frontal and sagittal plane movement control during jump-landings.

4. Stiff landings, with less knee flexion and greater vertical ground reaction force were associated with ACL injury risk in young female basketball and floorball players. Part of the measures to prevent ACL injuries in young female team sport players should focus on avoiding stiff landing patterns by teaching the players to increase knee flexion during landing and cutting movements. Better screening tests are needed because the currently used double-leg jump-landing test may not be able to identify athletes at risk for ACL injuries with sufficient accuracy.

YHTEENVETO (FINNISH SUMMARY)

Liikehallinnan merkitys vammojen ehkäisyssä nuorilla palloilulajien urheilijoilla

Liikuntavammat ovat yleisin tapaturmatyyppi Suomessa aiheuttaen vuosittain noin 143 000 lääkärissä käyntiä. Suurin osa liikuntavammoista tapahtuu nuorille henkilöille. Vammojen hoito ja kuntoutus aiheuttavat vuosittain suuret kustannukset. Liikuntavammoilla saattaa olla haitallisia pitkäkestoisia terveysvaikutuksia ja ne saattavat lopettaa liikunnan harrastamisen. Liikunta on välttämätöntä lapsen ja nuoren normaalille kehittymiselle ja tämän vuoksi vammoja on tärkeä pyrkiä ehkäisemään.

Koripallo ja salibandy ovat suosittuja joukkueurheilulajeja suomalaisten nuorten keskuudessa. Valitettavasti näissä lajeissa tapahtuu paljon vammoja. Hyvä liikehallinta on tärkeää palloilulajeissa, jotka sisältävät nopeita suunnanmuutoksia, jarrutuksia, kiihdytyksiä ja hypyistä laskeutumisia. Puutteellinen liikehallinta voi aiheuttaa liiallista kuormitusta nivelille ja saattaa lisätä loukkaantumisriskiä sekä akuuttien vammojen että rasitusvammojen osalta.

Vammoja ehkäisevän harjoittelun tulisi olla osa jokaisen kasvavan nuoren liikuntaharjoittelua. Vammojen ehkäisyn tehokkuutta voidaan lisätä selvittämällä vammoille altistavat riskitekijät ja kohdentamalla harjoittelua etenkin niille urheilijoille, joilla on suurentunut vammariski.

Tämän väitöskirjatutkimuksen tarkoituksena oli tutkia urheiluvammojen ehkäisyä, rasitusvammojen yleisyyttä ja vakavuutta, sekä liikehallinnan yhteyttä vakaviin polvivammoihin nuorilla palloilulajien urheilijoilla. Tutkimus koostui kahdesta osasta, joista ensimmäinen oli laaja systemaattinen kirjallisuuskatsaus ja yhteenvetotutkimus urheiluvammojen ehkäisystä tehdyistä satunnaistetuista kontrolloiduista tutkimuksista. Toinen osa tutki nuorten koripallon ja salibandyn pelaajien (n=401) rasitusvammojen yleisyyttä ja vakavuutta, pelaajien liikehallintaa ja suoritustekniikkaa kahden jalan pudotushypystä laskeutumisen aikana sekä polven eturistisidevammojen riskitekijöitä nuorilla naispelaajilla.

Laaja yhteenvetotutkimus osoitti, että urheiluvammoja voidaan tehokkaasti ehkäistä erilaisilla hermolihasjärjestelmän toimintaa kehittävillä harjoitusohjelmilla. Nämä sisälsivät urheilijoiden tasapainoa, ketteryyttä ja voimaominaisuuksia parantavia osioita. Harjoitteet voidaan toteuttaa ilman kalliita apuvälineitä osana alku- ja loppuverryttelyjä.

Tutkimuksen toinen vaihe osoitti, että etenkin polven ja alaselän rasitusvammat ovat yleisiä nuorilla koripallon ja salibandyn pelaajilla ja voivat aiheuttaa pitkiä poissaoloja täysipainoisesta harjoittelusta ja peleistä. Pelaajien liikehallinta kahden jalan pudotushypyn aikana osoittautui heikoksi molemmissa lajeissa. Puutteellisen liikehallinnan havaittiin olevan erittäin yleistä etenkin tytöillä.

Kolmen pelikauden pituinen seurantatutkimus osoitti, että vähäisempi polven koukistuminen hypyn alastulossa sekä suurentunut hyppyalustasta mitattu voima laskeutumisvaiheen aikana lisäsivät polven eturistisidevamman riskiä nuorilla naiskoripalloilijoilla ja -salibandypelaajilla. Toisin sanoen, pelaajat, jotka eivät keventäneet alastuloa joustamalla polvista, olivat suuremmassa riskissä saada eturistisidevamma kuin pelaajat, jotka laskeutuivat pehmeämmin. Polven valgusliikkeen eli sisäänpäin kääntymisen ei havaittu olevan itsenäisenä tekijänä yhteydessä eturistisidevammoihin, mikä johtunee osittain lisääntyneen valguksen yleisyydestä nuorilla naispalloilijoilla. Tutkimus osoitti myös, että kahden jalan pudotushyppy -testi ei ole riittävän herkkä ja tarkka tunnistamaan riskissä olevia urheilijoita, joten parempia liikehallintatestejä tulee jatkossa kehittää.

Tämän väitöskirjatutkimuksen perusteella liikehallinnan ja suoritustekniikan parantaminen sekä jarruttavan liikkeen lisääminen hypyistä alastulojen ja suunnanmuutosten aikana on tärkeää liikuntavammojen ehkäisyssä. Kohdennettua harjoittelua tarvitsevat etenkin nopeita suunnanmuutoksia ja jarrutuksia vaativien lajien nuoret harrastajat.

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APPENDIX I Characteristics of included RCTs.

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Balance board training								
Emery et al. 2005[e,f]	Home-based balance training	Students (50%)	14–19	66/61	6 mo	Sports injuries	OR, 0.16 [0.03 – 0.76][c]	6
Hupperets et al. 2009	Home-based propriocep-tive training	Athletes (52.5%)	12–70	256/ 266	1 y	Ankle sprains (recur.)	OR, 0.56 [0.38 – 0.82][c]	7
Mohammadi 2007	Propriocep-tive ankle disk training	Football players (100%)	24.6 (mean)	20/20	1 season	Ankle sprains (recur.)	OR, 0.08 [0.01 – 0.71][c]	3
Söderman et al. 2000[e]	Balance-board training	Football players (0%)	15–25	121/ 100	7 mo	LE injuries	OR, 1.25 [0.62 – 2.52][c]	3
Tropp et al. 1985[e]	Ankle disk training	Senior football players (100%)	NR	144/ 180	6 mo	Ankle sprains	OR, 0.24 [0.10 – 0.57][c]	3
Verhagen et al. 2004	Balance board training	Volley-ball players (42.9%)	21–27	641/ 486	36 wk	Ankle injuries	OR, 0.58 [0.35 – 0.96][b]	4
Wester et al. 1996	Wobble board training	Athletes (60.4%)	25 (mean)	24/24	12 wk	Ankle sprains (recur.)	OR, 0.28 [0.08 – 0.96][c]	2

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Multi-intervention with balance board								
Eils et al. 2010	Proprio-ceptive training	Basketball players (59%)	14–43	96/ 102	1 season	Ankle injuries	OR, 0.32 [0.13 – 0.79][b]	4
Emery & Meeuwisse 2010[e,f]	Neuro-muscular training program	Indoor football players (42%)	13–18	481/ 537	1 y	All injuries	OR, 0.61 [0.41 – 0.91][c]	5
Emery et al. 2007[e,f]	Balance training program	High-school basketball players (50.4%)	12–18	494/ 426	1 y	All injuries	OR, 0.72 [0.54 – 0.96][b]	5
McGuine & Keene 2006	Balance training program	High-school football and basketball players (31.6%)	16.5 (mean)	373/ 392	1 season	Ankle sprains	OR, 0.59 [0.35 – 1.02][c]	5
Pasanen et al. 2008[e,f]	Neuro-muscular training program	Floorball players (0%)	24 (mean)	256/ 201	6 mo	Acute non-contact LE injuries	OR, 0.34 [0.19 – 0.60][c]	8
Wedderkopp et al. 2003[e,f]	Ankle disk and functional strength training	Handball players (0%)	14–16	77/ 86	9 mo	Sports injuries	OR, 0.37 [0.14 – 1.00][b]	4
Wedderkopp et al. 1999[e]	Ankle disk and functional warm-up	Handball players (0%)	16–18	111/ 126	10 mo	Sports injuries	OR, 0.20 [0.10 – 0.41][c]	2

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Training interventions: Other multi-interventions								
Brushøj et al. 2008[g]	Preventive training program	Military soldiers (100%)	19–26	507/ 513	12 wk	LE injuries	OR, 1.26 [0.92–1.71][c]	7
Collard et al. 2010[e,f]	School-based physical activity program	Children (44.7%)	10–12	1117/ 1091	8 mo	Sports injuries	OR, 0.94 [0.70–1.25][c]	5
Ekstrand et al. 1983[e]	Prophylactic program	Senior football players (100%)	17–37	90/90	6 mo	Sports injuries	OR, 0.16 [0.08–0.30][b]	2
Heidt et al. 2000	Preseason training	Football players (100%)	14–18	42/ 258	12 mo	Sports injuries	OR, 0.33 [0.13–0.81][c]	3
Holme et al. 1999	Rehabilitation program	Recreation al athletes (62%)	21–32	46/46	12 mo	Recur. ankle sprains	OR, 0.18 [0.04–0.90][c]	3
Hägglund et al. 2007[e]	Coach-controlled rehabilitation program	Football players (100%)	15–46	282/ 300	1 season	All injuries Recur. injuries	OR, 0.30 [0.13–0.69][c]	6
Parkkari et al. 2011[e]	Neuro-muscular training with injury prevention counseling	Military conscripts (100%)	18–28	501/ 467	6 mo	Acute lower- and upper-limb injury	OR, 0.85 [0.63–1.14][c]	7
van Mechelen et al. 1993	Warm-up, cooldown, and stretching	Recreation al runners (100%)	NR	210/ 211	16 wk	LE and back injuries	OR, 1.31 [0.69–2.47][c]	2

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Warm-up programs								
Gilchrist et al. 2008[e]	Neuro-muscular warm-up program	Football players (0%)	20 (mean)	583/ 852	1 season	ACL injuries	OR, 0.29 [0.06–1.33][b]	4
LaBella et al. 2011[e,f]	Neuro-muscular warm-up program	High-school football and basketball players (0%)	16 (mean)	760/ 798	1 season	LE injuries	OR, 0.55 [0.38–0.80][c]	6
Longo et al. 2012[e]	'The FIFA 11+'	Basketball players (100%)	14 (mean)	80/41	9 mo	All injuries	OR, 0.30 [0.13–0.70][b]	8
Olsen et al. 2005[e,f]	Structured warm-up program	Handball players (13.7%)	15–17	958/ 879	8 mo	Ankle and knee injuries	OR, 0.53 [0.37–0.78][c]	7
Soligard et al. 2008[e,f]	Compre-hensive warm-up program	Football players (0%)	13–17	1055/ 837	8 mo	LE injuries	OR, 0.63 [0.48–0.82][c]	5
Steffen et al. 2008[e,f]	Core stability, balance, and eccentric hamstring strength	Football players (0%)	13–17	1091/ 1001	8 mo	All injuries	OR, 0.92 [0.74–1.15][c]	6
van Beijsterveldt et al. 2012[e]	'The 11'	Football players (100%)	18–40	223/ 233	9 mo	All injuries	OR, 1.04 [0.71–1.51][c]	5
Waldén et al. 2012[e]	Neuro-muscular warm-up	Football players (0%)	12–17	2479/ 2085	1 season	ACL injuries	OR, 0.42 [0.17–1.04][c]	8

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Strength training								
Askling et al. 2003	Eccentric hamstring training	Elite football players (100%)	25 (mean)	15/15	10 wk	Hamstring injuries	OR, 0.13 [0.02–0.66][c]	6
Gabbe et al. 2006	Eccentric exercise program	Australian football players (100%)	17–36	114/106	12 wk	Hamstring injuries	RR (NC), 1.2 [0.5–2.8]	5
Mohammadi 2007	Specific strength training of evertor muscles	Football players (100%)	24.6 (mean)	20/20	1 season	Recur. ankle sprains	OR, 0.38 [0.09–1.54][c]	3
Petersen et al. 2011[e,f]	Eccentric training program	Football players (100%)	23 (mean)	461/481	10 wk	Acute hamstring injuries	OR, 0.28 [0.15–0.50][c]	7
Running programs								
Bredeweg et al. 2012	Precondi-tioning program	Novice runners (34.5%)	38.1 (mean)	171/191	13 wk	Running-related injuries	OR, 0.89 [0.51–1.57][c]	6
Buist et al. 2008	Graded training program	Novice runners (42.5%)	39.8 (mean)	264/268	13 wk	Running-related injuries	OR, 1.03 [0.66–1.60][c]	4

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
			Insoles					
Finestone et al. 1999	Biomechanical shoe orthoses (custom)	Infantry recruits (100%)	17-27	260/144	14 wk	LE stress fractures	OR, 0.40 [0.19, 0.84][c]	4
Finestone et al. 2004	(1) Soft orthoses (custom) (2) Soft orthoses (prefabricated) (3) Semirigid biomechanical orthoses (custom) (4) Semirigid orthoses (prefabricated)	Infantry recruits (100%)	18-20	(1) 227 (2) 224 (3) 215 (4) 208	14 wk	LE overuse injuries	NC; no group differences	5
Franklyn-Miller et al. 2011	Foot orthoses	Military officer trainees (65%)	25 (mean)	200/200	7 wk	LE overuse injuries	OR, 0.27 [0.16, 0.46][c]	5
Larsen et al. 2002	Biomechanical shoe orthoses (custom)	Military conscripts (99.3%)	18-24	77/69	3 mo	Back and LE problems	RR, 0.70 [0.50-1.10] (NC)	7
Mattila et al. 2011	Orthotic insoles	Military conscripts (100%)	18-29	73/147	6 mo	LE overuse injury	OR, 1.42 [0.80, 2.50][c]	9
Milgrom et al. 1985	Shock-absorbing orthotic devices (prefabricated)	Military recruits (100%)	NR	143/152	14 wk	LE stress fractures	OR, 0.48 [0.29, 0.81][c]	3
Schwellnus et al. 1990	Insoles (prefabricated)	Military recruits (NR)	17-25	250/1261	9 wk	LE overuse injuries	OR, 0.69 [0.49, 0.96][b]	3
Smith et al. 1985	(1) Insole A (prefabricated) (2) Insole B (prefabricated) (3) Control	Coast guard recruits (NR)	17-25	(1) 30 (2) 30 (3) 30	8 wk	LE injuries	(1) vs (3) OR, 0.21 [0.06, 0.74][c] (2) vs (3) OR, 0.10 [0.02, 0.44][c]	2
Withnall et al. 2006	(1) Shock absorbing insole A (2) Shock absorbing insole B (3) Non-shock absorbing insole (control)	Military recruits (77.8%)	16-35	(1) 421 (2) 383 (3) 401	8 mo	Any LE injury	(1) and (2) vs (3) OR,1.04 [0.76, 1.42][c]	6

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
External Joint Supports								
Amoroso et al. 1998	Outside-the boot braces	Military para-troopers (100%)	>18	369/376	1 wk	Ankle injuries	OR, 0.50 [0.17–1.49][c]	6
McGuine et al. 2011[e,f]	Lace-up ankle braces	High-school basketball players (49.6%)	16 (mean)	740/720	1 season	Acute ankle injuries	OR, 0.31 [0.20–0.50][c]	3
McGuine et al. 2012[e,f]	Lace-up ankle braces	High-school American football players (NR)	NR	993/ 1088	1 season	Acute ankle injuries	OR, 0.42 [0.27–0.66][b]	3
Machold et al. 2002	Wrist pro-tectors	Students (60%)	14.8 (mean)	342/379	1 wk	Wrist injuries	OR, 0.12 [0.02–0.96][c]	5
Mohammadi 2007	Ankle orthoses	Football players (100%)	24.6 (mean)	20/20	1 season	Recur. ankle sprains	OR, 0.17 [0.03–0.92][c]	3
Rønning et al. 2001	Wrist pro-tectors	Snow-boarders (64.2%)	10-68	2515/ 2514	3 mo	Wrist injuries	OR, 0.27 [0.12–0.60][c]	7
Sitler et al. 1990	Knee braces	Military academy cadets (NR)	18-21	691/705	2 y	Knee injuries	OR, 0.43 [0.24–0.78][c]	4
Sitler et al. 1994	Semi-rigid ankle stabi-lizers	Military academy cadets (NR)	18-21	789/812	2 y	Ankle injuries	OR, 0.31 [0.16–0.62][c]	3
Surve et al. 1994	Sport-Stirrup ankle orthoses	Senior football players (100%)	NR	244/260	1 season	Ankle sprains	OR, 0.60 [0.40–0.91][c]	2
Tropp et al. 1985[e]	Ankle orthoses	Senior football players (100%)	NR	124/180	6 mo	Ankle sprains	OR, 0.16 [0.04–0.70][c]	3

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Stretching								
Bello et al. 2011	Rhytmic stabilisation (RS) streching technique	Indoor football players (NR)	18-27	7/7	4 mo	LE injuries	NC; no group differences	2
Jamtvedt et al. 2010	Stretching program	Active adults (36.4%)	40 (mean)	1220/ 1157	12 wk	Any LE or back injury	OR, 0.89 [0.75– 1.07][c]	4
Pope et al. 1998[e,g]	Pre-exercise calf muscle stretching	Army recruits (100%)	17-35	594/ 544	12 wk	LE injuries	OR, 0.87 [0.49–1.57][c]	4
Pope et al. 2000[e,g]	Lower extremity stretching program	Army recruits (100%)	17-35	735/ 803	12 wk	LE injuries	OR, 0.98 [0.77–1.25][c]	5
Protective Head Equipment								
Barbic et al. 2005[e,f]	Type II (boil-and-bite) mouth guard	University students (81%)	20.9 (mean)	322/ 324	3 mo	Concus-sions	OR, 1.04 [0.56–1.94][c]	4
Finch et al. 2005[e,f]	Custom-made mouth guard	Australian football players (100%)	15-31	190/ 111	1 season	Head/ Orofacial injuries	RR (NC), 0.56 [0.32–0.97]	4
McIntosh et al. 2009[e,f]	(1) Standard headgear (2) Modified padded headgear (3) Control	Rugby union players (100%)	<20	(1) 1128 (2) 1474 (3) 1493	2 seasons	Head injury or concussion	(1) vs (3) OR, 0.98 [0.77–1.24][b] (2) vs (3) OR, 1.14 [0.92–1.40][b]	3

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Modified Shoes								
Barrett et al. 1993	(1) High-top shoes (2) High-top shoes with air chambers (3) Low-top shoes	College basketball players (91.7%)	20.6 (mean)	(1) 227 (2) 212 (3) 183	2 mo	Ankle sprains	(1) vs (3) OR, 1.34 [0.39, 4.66]c (2) vs (3) OR, 0.77 [0.19, 3.14]c	4
Finestone et al. 1992	Modified basketball shoes	Infantry recruits (100%)	18-20	187/ 203	14 wk	LE overuse injuries	NC; no group differences	2
Kinchington et al. 2011	Tailored footwear program	Professional rugby players (100%)	24 (mean)	32/27	30 wk	LE injuries	NC; result favors intervention	3
Milgrom et al. 1992	Modified basketball shoes	Infantry recruits (100%)	NR	187/ 203	14 wk	LE stress fractures	OR, 1.28 [0.80, 2.05]c	2
Videos								
Arnason et al. 2005[d]	Video-based awareness program	Football players (100%)	NR	127/ 144	5 mo	Sports injuries	OR, 1.42 [0.84, 2.41]b	3
Cusimano et al. 2013	Ski and snowboard injury prevention program	Students (NR)	11-12	35/34	NR	All injuries	OR, 0.45 [0.08, 2.66]c	6
Jørgensen et al. 1998	Instructional ski video	Downhill skiers (58%)	5-61	243/ 520	1 wk	Sports injuries	OR, 0.64 [0.43, 0.96]c	3
Other Interventions								
Lappe et al. 2008	Calcium and vitamin D supplem.	Navy recruits (0%)	17-35	2626/ 2575	8 wk	Stress fractures	OR, 0.80 [0.67, 0.97]b	9

(continues)

APPENDIX I Characteristics of included RCTs (continues).

Abbreviations: CI, confidence interval; NC, not calculated; NR, not reported; OR, odds ratio; RR, risk ratio; LE, lower extremity; ACL, anterior cruciate ligament.
[a] Comparison is made with a control group that has not participated in any intervention (except for Finestone et al., Barrett et al. and Bello et al.).
[b] Calculated by using the number of injured individuals in the intervention vs control groups.
[c] Calculated by using the number of injuries in the intervention vs control groups.
[d] Calculated by using detailed information received from the authors.
[e] Cluster randomized.
[f] Cluster randomization was taken into account in the analyses of the original report.
[g] Quasi-randomized.

APPENDIX II Methodological quality assessment of included trials.

Study	A1	B2	C3	C4	C5	D6	D7	E8	F9	F10	F11	F12	TOT
Amoroso et al. 1998	YES	US	US	US	YES	NO	US	YES	YES	US	YES	YES	6
Arnason et al. 2005	US	US	US	US	US	YES	NO	YES	US	US	US	YES	3
Askling et al. 2003	US	US	US	US	YES	YES	US	YES	YES	US	YES	YES	6
Barbic et al. 2005	US	US	NO	NO	NO	NO	NO	YES	YES	US	NO	YES	3
Barrett et al. 1993	YES	US	US	US	US	YES	US	YES	US	US	US	YES	4
Bello et al. 2011	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Bredeweg et al. 2012	YES	US	US	US	US	YES	YES	YES	YES	US	NO	YES	6
Brushoj et al. 2008	NO	YES	YES	US	YES	NO	US	YES	YES	US	YES	YES	7
Buist et al. 2008	YES	US	US	US	US	YES	YES	YES	NO	US	NO	US	4
Collard et al. 2010	YES	US	NO	NO	NO	YES	YES	YES	NO	US	US	YES	5
Cusimano et al. 2013	YES	US	NO	NO	NO	YES	YES	YES	US	US	YES	YES	6
Eils et al. 2010	YES	US	US	US	US	YES	US	YES	US	US	US	YES	4
Ekstrand et al. 1983	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Emery et al. 2005	YES	US	US	US	US	YES	YES	YES	YES	US	US	YES	6
Emery & Meeuwisse 2010	US	US	YES	US	YES	NO	YES	YES	NO	US	US	YES	5
Emery et al. 2007	YES	US	US	US	YES	US	US	YES	YES	US	NO	YES	5
Engebretsen et al. 2008	US	US	US	US	US	YES	YES	YES	US	NO	NO	YES	4
Finch et al. 2005	US	US	NO	NO	NO	YES	YES	YES	US	NO	US	YES	4
Finestone et al. 1992	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Finestone et al. 1999	YES	US	US	US	US	NO	NO	YES	US	US	YES	YES	4
Finestone et al. 2004	YES	US	YES	NO	NO	NO	US	YES	US	US	YES	YES	5
Franklyn-Miller et al. 2011	YES	US	NO	NO	NO	YES	YES	YES	US	US	US	YES	5
Gabbe et al. 2006	YES	NO	US	US	NO	US	YES	YES	YES	US	NO	YES	5

(continues)

APPENDIX II Methodological quality assessment of included trials (continues).

Study	A1	B2	C3	C4	C5	D6	D7	E8	F9	F10	F11	F12	TOT
Gilchrist et al. 2008	US	US	US	US	US	NO	NO	YES	YES	US	YES	YES	4
Heidt et al. 2000	US	US	US	US	YES	US	US	YES	US	US	US	YES	3
Holme et al. 1999	YES	US	US	US	US	NO	US	YES	NO	US	US	YES	3
Hupperets et al. 2009	US	YES	US	US	YES	YES	YES	YES	YES	NO	NO	YES	7
Hägglund et al. 2007	US	YES	NO	NO	YES	YES	YES	YES	US	US	NO	YES	6
Jamtvedt et al. 2010	YES	US	NO	US	US	US	YES	YES	US	US	NO	YES	4
Jørgensen et al. 1998	US	US	US	US	US	US	US	YES	YES	US	US	YES	3
Kinchington et al. 2011	US	US	US	US	US	YES	NO	YES	US	NO	US	YES	3
LaBella et al. 2011	YES	YES	US	NO	NO	YES	YES	YES	NO	US	US	YES	6
Lappe et al. 2008	YES	YES	YES	YES	YES	NO	YES	YES	YES	US	US	YES	9
Larsen et al. 2002	YES	US	US	YES	US	YES	YES	YES	US	US	YES	YES	7
Longo et al. 2012	YES	YES	NO	NO	YES	YES	YES	YES	NO	US	YES	YES	8
Machold et al. 2002	YES	US	US	US	US	US	YES	YES	US	US	YES	YES	5
Mattila et al. 2011	YES	US	US	YES	YES	YES	YES	YES	YES	US	YES	YES	9
McGuine & Keene 2006	US	YES	NO	NO	US	NO	YES	YES	YES	US	US	YES	5
McGuine et al. 2011	US	US	NO	NO	NO	YES	YES	US	US	US	US	YES	3
McGuine et al. 2012	US	US	NO	NO	NO	YES	YES	US	US	US	US	YES	3
McIntosh et al. 2009	US	US	US	US	US	YES	YES	YES	US	US	NO	US	3
Milgrom et al. 1985	US	US	US	US	US	YES	US	YES	US	US	US	YES	3
Milgrom et al. 1992	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Mohammadi 2007	US	US	US	US	US	YES	US	YES	US	US	NO	YES	3
Olsen et al. 2005	US	YES	US	US	YES	YES	YES	YES	US	NO	YES	YES	7
Parkkari et al. 2011	YES	YES	NO	NO	YES	NO	YES	YES	NO	US	YES	YES	7
Pasanen et al. 2008b	YES	YES	NO	NO	YES	YES	YES	YES	YES	US	NO	YES	8

(continues)

APPENDIX II Methodological quality assessment of included trials (continues).

Study	A1	B2	C3	C4	C5	D6	D7	E8	F9	F10	F11	F12	TOT
Petersen et al. 2011	YES	YES	NO	NO	NO	YES	US	YES	YES	US	YES	YES	7
Pope et al. 1998	US	YES	YES	US	US	NO	US	YES	US	US	US	YES	4
Pope et al. 2000	US	YES	US	US	YES	NO	YES	YES	US	US	US	YES	5
Rønning et al. 2001	US	US	US	US	YES	YES	YES	YES	YES	US	YES	YES	7
Schwellnus et al. 1990	US	US	US	US	US	US	US	YES	US	US	YES	YES	3
Sitler et al. 1990	YES	US	US	US	US	US	US	YES	US	US	YES	YES	4
Sitler et al. 1994	US	US	US	US	US	US	US	YES	US	US	YES	YES	3
Smith et al. 1985	US	US	US	US	US	NO	US	YES	US	US	US	YES	2
Soligard et al. 2008	US	YES	NO	NO	YES	NO	YES	YES	US	US	US	YES	5
Steffen et al. 2008	US	YES	NO	NO	YES	YES	YES	YES	US	US	NO	YES	6
Surve et al. 1994	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Söderman et al. 2000	US	US	US	US	US	NO	NO	YES	YES	US	NO	YES	3
Tropp et al. 1985	US	US	US	US	US	YES	US	YES	US	US	US	YES	3
van Beijsterveldt et al. 2012	YES	US	NO	NO	NO	YES	US	YES	NO	US	YES	YES	5
van Mechelen et al. 1993	US	US	US	US	US	NO	US	YES	US	US	NO	YES	2
Verhagen et al. 2004	US	US	US	US	YES	NO	US	YES	YES	US	US	YES	4
Waldén et al. 2012	YES	YES	NO	NO	YES	YES	YES	YES	YES	US	US	YES	8
Wedderkopp et al. 1999	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Wedderkopp et al. 2003	US	US	US	US	NO	YES	YES	YES	US	US	US	YES	4
Wester et al. 1996	YES	US	US	US	US	NO	US	YES	US	US	US	NO	2
Withnall et al. 2006	YES	YES	NO	NO	NO	YES	YES	YES	US	US	US	YES	6

(continues)

APPENDIX II Methodological quality assessment of included trials (continues).

A1, adequate randomization (yes = random assignment was performed by using a computer-generated random sequence, pre-ordered sealed envelopes, or another clearly described and acceptable random method).
B2, concealed allocation (yes = assignment was generated by an independent person not responsible for determining the eligibility of the study participants).
C3, blinding of the study participants (yes = the index and control groups were indistinguishable for the study participants).
C4, blinding of the care providers (yes = the index and control groups were indistinguishable for the care providers (e.g. physicians, physiotherapists, trainers) involved in the study).
C5, blinding of the outcome assessors (yes = physicians, physiotherapists, radiologists, researchers, and other staff who evaluated the injuries were blinded regarding group assignment).
D6, described and acceptable drop-out rate (yes = drop-out rate was < 20% for short-term follow-up [0-3 months] or < 30% for long-term follow-up [over 3 months] and reasons for drop-out was given).
D7, intention-to-treat analysis (yes = all randomized participants were analyzed in the group they were allocated to by randomization irrespective of non-compliance and co-interventions).
E8, reports of the study free of suggestion of selective outcome reporting (yes = published report includes enough information and all the results from outcomes have been adequately reported).
F9, similarity between groups at baseline (yes = study groups were similar at baseline regarding demographic factors and other important prognostic factors).
F10, avoided or similar co-interventions (yes = there were no co-interventions or they were similar between the index and control groups).
F11, acceptable compliance (yes = compliance was regularly checked or otherwise supervised and it was more than 70% in every study group).
F12, similar timing of the outcome assessment (yes = duration of the intervention was similar for all study groups).
YES, criterion was described and acceptable (1 point).
NO, criterion was not acceptable (0 points).
US, unsure, criterion was unclear or not described adequately (0 points).
TOT, total points of quality assessment (maximum of 12 points) (Furlan et al. 2009).

APPENDIX III Characteristics of effective training interventions.

Study	Intervention	Athletes	Adults	Adolescents	Males	Females	Pre-season	On season	Home-based	Warm-up	Stretching	Balance / Coordination	Strength / power	Equipment	Progressive	Other
Askling et al. 2003	Eccentric strength training program	x	x		x		x						x	Resistance training		
Emery et al. 2005	Home-based balance training program			x	x	x			x			x		Balance board		
Hupperets et al. 2009	Home based proprioceptive training program	x	x	x	x	x			x			x		Balance board		
Mohammadi 2007	Proprioceptive training program	x	x		x			x				x		Balance board	x	
Tropp et al. 1985	Ankle disk training	x	x		x		x	x				x		Balance board		
Verhagen et al. 2004	Balance board training program	x	x		x	x		x		x		x		Balance board, ball	x	
Eils et al. 2010	Multistation proprioceptive exercise program	x	x	x	x	x		x				x			x	
Emery & Meeuwisse 2010	Neuromuscular training program and home-based balance training program	x		x	x	x			x	x	x	x	x	Balance board		
Emery et al. 2007	Basketball-spesific balance training program	x		x	x	x		x	x	x		x		Balance board	x	
Pasanen et al. 2008b	Neuromuscular training program	x	x			x		x		x		x	x	Balance board, balance pad, medicine ball	x	

(continues)

APPENDIX III Characteristics of effective training interventions (continues).

Study	Intervention	Athletes	Adults	Adolescents	Males	Females	Pre-season	On season	Home-based	Warm-up	Stretching	Balance / Coordination	Strength / power	Equipment	Progressive	Other
Wedderkopp et al. 1999	Ankle disk and functional warm-up training	x		x		x		x		x		x		Balance board		
Wedderkopp et al. 2003	Ankle disk and functional strength training	x		x		x		x		x		x	x	Balance board		
Ekstrand et al. 1983	Prophylactic program	x	x		x			x		x	x			Insoles, taping		Controlled rehabilitation, correction and supervision
Heidt et al. 2000	Preseason training program	x		x		x	x					x	x	Treadmill	x	
Holme et al. 1999	Rehabilitation program	x	x		x	x						x	x	Balance board		Supervised physical therapy
Hägglund et al. 2007	Coach-controlled rehabilitation program	x	x		x								x		x	
LaBella et al. 2011	Neuromuscular warm-up program	x		x		x		x		x		x	x			
Longo et al. 2012	Warm-up program me (The FIFA 11+)	x	x	x	x			x		x	x	x	x			
Olsen et al. 2005	Structured warm-up program	x		x	x	x		x		x		x	x	Balance mat, balance board	x	
Soligard et al. 2008	Comprehensive warm-up program (The FIFA 11+)	x		x		x		x		x		x	x			
Petersen et al. 2011	Eccentric training program	x	x		x								x		x	

ORIGINAL PUBLICATIONS

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INTERVENTIONS TO PREVENT SPORTS RELATED INJURIES: A SYSTEMATIC REVIEW AND META-ANALYSIS OF RANDOMISED CONTROLLED TRIALS

by

Mari Leppänen, Sari Aaltonen, Jari Parkkari, Ari Heinonen & Urho M. Kujala
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Interventions to prevent sports related injuries: a systematic review and meta-analysis of randomised controlled trials

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ABSTRACT

Background The effects of methods to prevent injuries have been studied in several systematic reviews. However, no meta-analysis taking into account all randomised controlled intervention trials aiming at the prevention of sports injuries has been published.

Objective To summarise the effects of sports injury prevention interventions.

Design Systematic review and meta-analysis of randomised controlled trials.

Data sources PubMed, MEDLINE, SPORTDiscus, the Cochrane Central Register of Controlled Trials, CINAHL, PEDro, and Web of Science, searched in September 2013. The reference lists of retrieved articles and reviews were hand searched.

Eligibility criteria for selecting studies To be selected articles had to examine the effects of any preventive intervention on sports injuries, be randomised/quasi-randomised and controlled trials, published in a peer-reviewed journal. The outcome of the trial had to be injury rate or the number of injured individuals.

Results Of the 5580 articles retrieved after a search of databases and the relevant bibliography, 68 randomised controlled trials were included in the systematic review and 60 trials were included in the meta-analysis. Insoles (OR 0.51, 95%CI 0.32 to 0.81), external joint supports (OR 0.40, 95%CI 0.30 to 0.53), and specific training programmes (OR 0.55, 95%CI 0.46 to 0.66) appeared to be effective in reducing the risk of sports injuries. Stretching (OR 0.92, 95%CI 0.80 to 1.06), modified shoes (OR 1.23, 95%CI 0.81 to 1.87), and preventive videos (OR 0.86, 95%CI 0.44 to 1.68) seemed not to be effective.

Conclusions This meta-analysis showed that certain interventions can reduce the risk of sports injuries. There were limitations regarding the quality of the trials, generalisability of the results, and heterogeneity of the study designs. In future, the mechanisms behind effective methods and the most beneficial elements of preventive training programmes need to be clarified.

1 INTRODUCTION

Although physical activity has multiple health benefits participation in sports also carries a risk of injury. Sports-related injuries are detrimental to an injured athlete's health [1], may cause permanent disability, or even terminate the athlete's sports career [2]. Injuries also burden the health care system as the treatment of sports injuries is often demanding and expensive [1, 3]. Injury prevention research is needed to promote safe participation in exercise [1, 4].

In the last ten years, the number of published sports injury prevention studies has increased [4-5]. The effects of several interventions aiming to prevent sports injuries have been studied in RCTs. Earlier RCTs have been more concerned with protective equipment, such as insoles and external joint supports, but recently an increased number of training programmes and multi-interventions have been studied [4-5]. The effects of injury prevention methods have been studied in several systematic reviews earlier [6-21]. Some of the reviews have included only RCTs, but a few have also included other controlled trials. These earlier reviews have summarised the effects of specific injury prevention methods or prevention of specific types of injuries. As far as we know, the study by Aaltonen et al. [22] is the only systematic review of RCTs summarising the effects of all randomised controlled interventions intended to prevent sports injuries. Since then, many new trials have been published. Although the number of systematic reviews published is quite large, they have seldom included meta-analyses due to the small number of homogeneous studies.

Due to an increase in the number of sports injury prevention trials, what is known about preventing sports injuries needs updating. The aim of the study was to update and summarise the effects of preventive interventions.

2 METHODS

2.1 Search strategy

The literature search for this study was conducted by combining two independent, similarly conducted search processes. The first search was conducted by Aaltonen et al. [22] until December 31, 2005 and is described elsewhere. The second literature search was accomplished using the same search strategy as Aaltonen and co-workers, except that it began from 1 January 2006.

The systematic literature search was conducted in September 2013. Relevant trials were searched for in the following databases: PubMed, MEDLINE (Ovid), SPORTDiscus, the Cochrane Central Register of Controlled Trials, CINAHL (Cumulative Index to Nursing and Allied Health Literature), PEDro (the Physiotherapy Evidence Database), and Web of Science. The update search was conducted from 1 January 2006, to 24 September 2013. The following key words were used in the search: sports injury/ies, athletic injury/ies, prevention, preventive, randomiz/s/ed, controlled trial, and randomiz/s/ed controlled trial. Various combinations of the search terms were used. In addition, the reference lists of articles retrieved and relevant reviews were hand searched.

2.2 Trial selection

The electronic search process yielded in total 5580 articles (4803 items in the first search and 777 in the second). The retrieved articles were first assessed on the basis of titles and abstracts. After the first screening, 5462 articles (4755 and 707) were excluded. The remaining 118 potentially eligible articles (48 and 70) were evaluated more thoroughly on the basis of the full article. Relevant reviews and reference lists of retrieved articles were searched hand searched, and two studies were included as a result of the hand search. Altogether 68 trials (32 and 36) were included in the present systematic review. Eight trials could not be pooled for meta-analysis due to lack of sufficient data. Thus, 60 trials provided adequate data and were included in the meta-analysis. The literature search is presented as a flow chart in **Fig. 1**.

2.3 Inclusion criteria

Selected articles, published in English, had to examine the effects of any preventive intervention in sports injuries. The trials selected had to be randomised or quasi-randomised (the authors have acknowledged that the used randomisation procedure does not fulfill the current methodological recommendations of randomisation) controlled trials, and published in a peer-reviewed journal. In the second search, during the hand search of the reference lists of relevant reviews and retrieved articles, also articles published before 2006 were included if they met other inclusion criteria. The outcome of the trial had to be injury rate or the number of injured individuals. To maximize the information we can get from the literature we included studies on athletes from recreation to elite levels and from different sports disciplines as well as studies on military recruits although the target groups of the specific studies need to be taken into account when generalising the results.

2.4 Exclusion criteria

Trials were excluded if they were not randomised, if there were no control group, or if the outcome was other than sports injuries. Also abstracts without the full text available were excluded. The study report had to contain adequate information about the trial protocol and the injury rate or the number of injured individuals as an outcome. One article was excluded because the article had been retracted afterwards on the basis of ethical reasons.

2.5 Data extraction

Data from each study included was extracted from on the full text. In case of insufficient data, the authors were contacted via email. The study design, description of the intervention, characteristics of participants, and main outcomes from each article were extracted, and are presented in **Electronic Supplementary Material Table S1**.

Calculations for meta-analysis were made with Cochrane Collaboration Review Manager 5.1 software. All calculations were made according to the primary outcomes of the studies. The calculations were primarily based on the number of injured individuals in the intervention group and in the control group. If the number of injured individuals was not available, the number of injuries was used instead. Odds ratios (OR) with 95% confidence interval were used as the effect measure, the statistical method was inverse variance, and the analysis model was based on random effects. Statistical heterogeneity (I^2) and test for overall effect was calculated and p-values < 0.05 were regarded as statistically significant.

2.6 Methodological quality assessment of the selected trials

Methodological quality assessment of the included trials (**Electronic Supplementary Material Table S2**) was made as recommended by Furlan et al. [23]. The quality assessment was made independently by two authors. In case of disagreement, consensus was found through discussion. The quality assessment list consists of 12 criteria: method of randomisation, concealed allocation, blinding of participants, blinding of care providers, blinding of outcome assessors, drop-out rate, analysis according to allocated group, reporting without selective outcome, baseline similarity of the groups, co-interventions, compliance, and timing of outcome assessment. Each criterion was scored as 'yes', 'unclear' or 'no', and 'yes' indicated one point. The studies were rated as having a low risk of bias when at least six out of twelve points were scored, and study had no other serious flaws (e.g. high drop-out rate in one group or compliance threshold less than 50% of the criteria) [23]. Studies were rated as having a high risk of bias if fewer than six points were scored, or if a study had one or more serious flaws. Studies were not excluded due to low scores on methodological quality.

3 RESULTS

Altogether, 68 randomised controlled trials examining the effects of preventive intervention on sports injuries were discovered through a systematic literature search [24-92]. The results of the methodological quality assessment are presented in **Electronic Supplementary Material Table S2**. The highest score a study received was 9/12 and the lowest 2/12. The average score received was 5/12.

Trials were divided into seven groups (insoles, external joint supports, training programmes, stretching, protective head equipment, modified shoes, and injury prevention videos) according to the type of the intervention. Some groups were further divided into subgroups according to intervention characteristics. This was done even though there might have been some heterogeneity in interventions and in methodological issues between the studies. Note that five trials [24-28] had two or more intervention groups tested, but only one control group. These interventions were pooled as individual trials. Therefore, in the forest plots, the number of participants in the control groups of these trials is actually multiple. Seven of the included trials [29-35] could not be pooled due to insufficient injury data. In addition, one included study [36] could not be pooled to any sub-group of studies because it was the only study to assess the effects of dietary supplements on sports injury risk.

3.1 Insoles

Nine of the trials [24, 30-31, 37-38, 62-63, 73, 79] studied the effects of insoles to reduce the risk of lower limb injuries among military recruits (total of 4788 subjects). In the study by Smith et al. [24] two different types of insoles were used, and these interventions were treated as individual trials. Eight individual interventions were pooled and six of these yielded effective results. Although two interventions [37-38] failed to show preventive effect, test for overall effect (Z= 2.83, p= 0.005) remained statistically significant, and insoles significantly reduced the risk of injuries (pooled OR 0.51, 95% CI 0.32 to 0.81). Heterogeneity between the studies was strong (I^2= 82%, p< 0.001) (**Fig. 2**). Two studies could not be pooled; the result from the study by Larsen et al. [30] favoured intervention (RR 0.70, 95% CI 0.50 to 1.10), whereas no group differences were observed in the study by Finestone et al. [31].

3.2 External joint supports

The effects of external joint supports were studied in ten trials (total of 13808 subjects). All seven interventions [25, 27, 39-41, 43, 46] assessing various ankle supports (ankle stabilizers, and outside-the-boot braces) reduced ankle injuries compared to no ankle supports (pooled OR 0.40, 95%CI 0.30 to 0.53) (**Fig. 3**). The subjects in these trials (total of 6662 subjects) were young male and female athletes in basketball, male athletes in football and American football, and military paratroopers.

In two trials [44-45] assessing wrist supports, in a total of 5750 subjects, wrist supports were effective in protecting snowboarders against wrist injury (pooled OR 0.25, 95%CI 0.12 to 0.51). Knee supports were studied in one trial [46] in which the use of prophylactic knee braces significantly reduced the number of knee injuries among 1396 military cadets while playing football (OR 0.43, 95%CI 0.24 to 0.78) (**Fig.3**).

According to ten trials studying the effects of external joint supports, the intervention group suffered significantly fewer injuries than the control group (pooled OR 0.39, 95%CI 0.31 to 0.49). Statistical heterogeneity between the studies was low (I^2= 13%, p= 0.32) (**Fig. 3**).

3.3 Training programmes

The effects of training intervention on sports injury prevention were studied in 37 of the trials included. These interventions were divided into six subgroups: balance board training, multi-intervention with balance board training, other multi-interventions, warm-up programmes, strength training, and graded running programmes (**Fig. 4**).

On the basis of seven trials [25, 27, 55, 67, 82, 85-86] (1922 subjects), balance board training significantly reduced the number of sports injuries in the intervention group compared to the control group (pooled OR 0.45, 95%CI 0.28 to 0.73). The results showed heterogeneity (I^2= 61%, p= 0.02). Examination of the studies investigating a multi-intervention with balance board training (3458 participants) yielded consistent results. Multi-interventions using balance board training were effective in reducing the risk of sports injuries (pooled OR 0.46, 95%CI 0.31 to 0.64). Moreover, other multi-intervention studies (5429 subjects) also achieved preventive effects (pooled OR 0.63, 95%CI 0.42 to 0.95), although the results were somewhat inconsistent, and heterogeneity was strong (I^2= 84%, p< 0.001).

Of the eight trials [64, 70-71, 74, 80-81, 87-88] investigating the effects of a warm-up programme (13817 subjects), statistically significant results were found in half of them (ORs from 0.29 to 0.92). However, the pooled result reached statistical significance; warm-up programmes tended to reduce the risk of sports injuries (pooled OR 0.64, 95%CI 0.49 to 0.83). The results showed statistically significant heterogeneity (I^2= 66%, p< 0.01).

The effects of strength training on the lower extremity injuries were assessed in four studies [27, 33, 47-48] (1232 subjects). In the studies by Askling et al. [47] and Petersen et al. [48] eccentric strength training significantly reduced the risk of hamstring injuries among football players, whereas Mohammadi [27] found no significant effect of strength training on the recurrence of ankle sprain. The combined results confirmed that strength training achieved a significant reduction in the risk of injuries in the intervention group compared to the control group (pooled OR 0.27, 95%CI 0.16 to 0.45). The results showed no heterogeneity (I^2= 0%, p= 0.59). The results of the study by Gabbe et al. [33] could not be pooled, but no differences were found in the rates of hamstring injuries between the intervention and control group (RR 1.2, 95%CI 0.5 to 2.8).

In the studies by Bredeweg et al. [49] and Buist et al. [50], a graded training programme in the prevention of running related injuries among novice runners (848 subjects) failed to show any preventive effects (pooled OR 0.97, 95%CI 0.69 to 1.38). No heterogeneity was observed (I^2= 0%, p= 0.69).

According to the 38 trials, training programmes were effective in reducing the risk of sports injuries (pooled OR 0.55, 95%CI 0.46 to 0.66). Heterogeneity between the studies was marked (I^2= 75%, p< 0.001) (**Fig. 4**).

3.4 Stretching

Four trials [34, 69, 77-78] investigated the effects of stretching on lower extremity injuries (total of 4812 participants). Stretching appeared to have no effect on the rate of injuries (pooled OR 0.92, 95%CI 0.80 to 1.06) (**Fig. 5**). There was no statistical heterogeneity between the studies. The study by Bello et al. [34] could not be pooled, but the results showed no differences in the risk of injury in a rhythmic stabilisation method from the normal stretching.

3.5 Protective head equipment

Three trials [28, 32, 51] (total of 5010 subjects) with four different comparisons studied the effects of protective head equipment on head injuries or concussions. In the study by McIntosh et al. [28], two different types of headgear were tested among 4095 rugby players, with no preventive effect (pooled OR 1.06, 95%CI 0.91 to 1.24). Similar results were found in the study by Barbic et al. [51], in which the use of mouth guards was not effective in reducing the rate of concussions among 614 university American football and rugby players (OR 1.04, 95%CI 0.56 to 1.94). Consequently, the pooled OR of protective head equipment was 1.06 (95%CI 0.91 to 1.24), with no statistical heterogeneity between the studies (I^2= 0%, p= 0.66) (**Fig. 6**). The results of the study by Finch et al. [32] with 301 Australian football players could not be pooled, but showed opposite results: custom-made mouth guards had a significant effect on the rates of head and orofacial injuries in the intervention group compared to the control group (RR 0.56, 95%CI 0.32 to 0.97).

3.6 Modified shoes

The effects of modified shoes on lower limb injuries were studied in four trials [26, 29, 35, 52] (total of 1408 subjects) with five different interventions. The results of the three individual comparisons were pooled, and are illustrated in **Fig. 7**. Barrett et al. [26] compared two different types of high-top basketball shoes to low-top shoes among basketball players. Milgrom et al. [52] studied modified basketball shoes among military recruits. None of these three interventions were able to show any reduction in the risk of injury (pooled OR 1.23, 95%CI 0.81 to 1.87). No heterogeneity was observed (I^2= 0%, p=0.79). In addition, two studies could not be pooled. In the study by Finestone et al. [29], no group differences were observed, but the results of the study by Kinchington et al. [35] investigating the effects of a tailored footwear programme, favoured the intervention group.

3.7 Injury prevention videos

Three interventions [53-54, 92] with injury prevention videos (total of 1103 subjects) yielded contradictory results. An instructional ski video reduced the injury risk in downhill skiers [53], whereas another ski and snowboard injury prevention program including video and brochure was not effective to reduce injuries in school-aged children [92]. Similarly, a video-based awareness programme had no effect on the rate of injuries among football players [54].There was considerable heterogeneity between the studies (I^2= 67%, p=0.05) and the combined effects of the injury prevention videos were not significant (pooled OR 0.86, 95%CI 0.44 to 1.68) (**Fig. 8**).

3.8 Other interventions

Lappe et al. [36] investigated the effects of calcium and vitamin D supplements on the incidence of stress fractures in female military recruits (total of 5201 subjects). The results showed that calcium and vitamin D supplements were effective in reducing the risk of stress fractures (OR 0.80, 95%CI 0.67 to 0.97) [36].

4 DISCUSSION

4.1 Principal findings

In our systematic review we included 68 RCTs examining the effects of various preventive interventions on the risk of sports injuries. Meta-analyses were conducted using 60 RCTs with 66 comparisons. According to the data available, insoles, external joint supports, and training programmes with different components appear to be effective in reducing the risk of sports injuries, whereas stretching, modified shoes, and injury prevention videos failed to show preventive effects.

4.2 Comparison to previous reviews

Orthotic insoles are widely used to prevent overuse injuries [38]; nevertheless, the evidence of their effectiveness has been inconsistent [38, 93]. Evidence from earlier reviews has shown that the use of orthotic insoles may prevent first-time lower limb injuries [9] and tibial stress fractures [93], and that shock-absorbing insoles may be effective in reducing the incidence of stress fractures [14]. However, insoles appear not to be effective in reducing lower limb soft-tissue running injuries [19]. In our meta-analysis, six of the eight pooled studies supported the use of insoles to prevent lower limb injuries, whereas the studies by Withnall et al. [37] and Mattila et al. [38] reported no preventive effects. Interestingly, the quality assessment of these trials revealed that only the trials by Withnall et al. and Mattila et al. were rated as having a low risk of bias, whereas the other trials had a high risk of bias. Although the pooled results showed a significant preventive effect, there is a potential risk of bias. These results therefore need to be interpreted with caution. The applicability of these results is moreover limited primarily to young men undergoing military training and cannot be directly generalized to athletes even though military training includes high-intensity physical training [22].

Trials assessing the effectiveness of external joint supports have mostly been conducted among subjects in high-risk sporting activities, such as football, basketball, American football, parachute jumping, and snowboarding. In all the trials included in the present meta-analysis except one, the use of external joint supports provided beneficial protection against ankle, knee, or wrist injuries. Interestingly, the statistical heterogeneity between the trials of external joint supports was very low, even though there were differences in the study designs, whereas in most of the other groups with multiple trials, heterogeneity was high. Ankle sprains have often been reported as the most common type of injury encountered in sports [15, 94]. The present finding of a preventive role of external ankle supports is consistent with earlier research [94-95, 15]. However, in the present analysis, the external ankle supports used were different kinds of stabilizing devices, such as orthoses and braces, but for instance taping, also reportedly effective for reducing ankle sprains [15, 94], was not studied in these RCTs. Although anterior cruciate ligament (ACL) injuries of the knee are a well-known problem, especially among female athletes participating in pivoting and cutting sports [96], the effects of prophylactic braces to reduce the incidence of knee injuries has not been commonly studied in RCTs. This is probably because earlier studies have reported a lack of evidence of their effectiveness in preventing ACL injuries [96], but also due to a growing interest in the effects of specific preventive training interventions to reduce the risk of lower extremity injuries. In this meta-analysis only one trial [46] demonstrated the effect of prophylactic knee braces and reported a reduced risk of knee injuries. Note that this trial was conducted among military recruits while playing football, and the reduction of knee injuries was dependent on a player's position. Based on one trial only, the implications of the effectiveness of knee bracing cannot be drawn.

The number of interventions assessing training programmes has increased nearly three-fold since the previous systematic review [22]. This reflects the current trend in sports injury research. Exposure to extrinsic risk factors, such as environmental conditions or other players, can seldom be influenced. Even though not all intrinsic risk factors can be changed, factors such as physical fitness, muscle strength, motor abilities and sports specific skills are highly trainable. Most of the training programmes designed for the prevention of injuries aim to influence these risk factors by enhancing athletes' intrinsic abilities. What makes the interpretation of these results complex is the variety of components used in training interventions.

An earlier systematic review of research on the prevention of sports injuries yielded preliminary findings of balance board training as a preventive strategy [22]. Since then seven new RCTs on balance board training alone or as a part of multi-intervention have been published. Balance training can improve both static and dynamic balance and enhance postural control during sports which may reduce the risk of injury [86], and moreover likely improve neuromuscular control. The present findings further support the benefits of balance board training. Balance board training seems to be effective especially in reducing the risk of ankle injuries, but also to some extent, when part of neuromuscular training, of other injuries of the lower extremities. However, when balance board training is combined with the other components of a multi-interventional training programme, the actual effect of the balance board remains unclear. Interestingly, data from **Electronic Supplementary Material Table S3** indicates that 80% of all effective training interventions included some sort of balance or coordination component. Five trials used balance board training as home-based training and four of these home-based interventions were demonstrably effective. At least among athletes frequently accustomed to also doing exercises in their leisure time, a home-based training intervention can be as effective as a supervised intervention.

According to the review by Fradkin et al. [7], the evidence of warming up has been insufficient. The present finding on the effectiveness of warm-up programmes is more promising, but still, to some extent contradictory. Although the pooled result showed a preventive effect, half of the trials failed to achieve significant results. The conflicting results may be attributable to the variety of training components used in these interventions. While using a wide spectrum of different types of exercises (e.g. balance, stretching and strength), it remains unclear which are the most beneficial components of a preventive intervention. Independent trials had some major limitations, such as lack of compliance in the study by Steffen et al. [87] and small number of events in the study by Waldén et al. [88], which could have influenced the pooled result. Most of the warm-up programmes were conducted among soccer players and included exercises intended to enhance neuromuscular control.

When dividing training interventions into subgroups, some overlap in the contents of the training programs used in each group was inevitable. Therefore a neuromuscular training method was included in many training interventions. It has been hypothesised that neuromuscular training can induce such changes within the neuromuscular system that may affect the risk of injuries [20, 89]. Neuromuscular training is thought to have beneficial effects on sense of joint position, stability, and reflexes [16, 20]. Also, according to recent review [20], neuromuscular training can be implemented effectively with no additional equipment, thereby offering a practical, cost-effective way to reduce the risk of injury.

Eccentric strength training, according to two high quality trials, seemed to reduce the risk of hamstring injuries among soccer players [47-48]. This finding is consistent with the other systematic review [10]. However, strength training was not effective among Australian football players [33], and among football players practicing strengthening the evertor muscles to reduce the recurrence of ankle sprains [27]. Interventions intended to increase strength and power have not yet been extensively studied in RCTs. Instead, strength and power training has successfully been used as a part of multicomponent interventions. Approximately half of the effective training multicomponent interventions included strength or power training components, and almost all of them combined elements from both strength and power, and balance and coordination training (**Electronic Supplementary Material Table S3**).

It is likely that the preventive effect of the training programmes using several components is the sum of individual effective methods. It is almost impossible to identify which part of the training intervention is the actual effective component and which part has no influence on the risk of injury [22]. The preventive effect may also be a result of the interaction of the different components, when two single elements may not be effective in isolation from each other, but have a desirable combined effect. Nevertheless, effective training programs require carefully planned injury specific exercises and the programmes need to be adjusted to the injury problem within the target population at hand. In addition, one major issue concerning the effectiveness of any intervention is compliance to the intervention. Knowing that high compliance can further reduce injury risk [97], the challenge is how to motivate athletes and their coaches to follow injury prevention program.

Stretching has not generally been studied in RCTs. In this review four RCTs studied the effectiveness of stretching and only three of these were eligible for inclusion in the meta-analysis. This limited number of trials is probably due to the existence of evidence from earlier studies implying that stretching has no effect on overall injury risk [98-99, 12]. The present finding does nothing to change to this. However, some reviews have stated that there is preliminary evidence that stretching may reduce the risk of musculotendinous strains [12, 100], and ligament sprains [12], but this needs further investigation. Evidently, the lack of well-conducted controlled trials is a problem, and therefore the definitive role of stretching cannot be confirmed [99-100].

Some of other methods, such as protective head equipment, modified shoes and injury prevention videos, have been studied even less in RCTs, and therefore drawing firm conclusions on their effectiveness is not reasonable. In addition, there were other limitations, such as poor compliance and co-interventions, affecting the results of individual trials.

4.3 Limitations and future studies

This study had some limitations. The quality assessment of the trials revealed various methodological weaknesses in the trials. The quality score varied between two and nine points out of 12 the average being five points. According to the recommendations of Furlan et al. [23], studies should be rated as having a low risk of bias when at least six of the 12 criteria have been met and the study has no serious flaws. Studies should be rated as having a high risk of bias if the score given is less than six or if the study has serious flaws [23]. Based on these recommendations, in this review, only 21 studies were rated as having a low risk of bias, whereas 47 studies were considered as having a high risk of bias. Under these circumstances, issues of the internal validity of the studies ought to be acknowledged. There is a possibility of selection bias because of inadequate concealment of allocation or baseline differences between groups in 64 trials (including all three quasirandomised trials); performance bias due to the lack of blinding of participants or care providers, the effect of co-interventions and inadequate compliance in all 68 trials; detection bias due to the lack of blinding of outcome assessors or different timing of the outcome assessment in 48 trials; and attrition bias due to lack of intention-to-treat analysis or unacceptable drop-out rate in 44 trials. Given the nature of interventions to prevent sports injuries, the blinding of the patients, care providers, and outcome assessors simultaneously, and avoiding co-interventions is in most cases extremely problematic. Therefore it is almost impossible for a study to attain the highest quality assessment score [22]. Of the 21 studies considered that have a low risk of bias, all except one were conducted in the

2000s, suggesting that studies are nowadays conducted and reported more correctly than before.

Furthermore, there were limitations in external validity. In general, most of the participants in the studies were young adult athletes, both male and female. Only a few of the studies included senior athletes or children. The studies involving the use of insoles in particular used exclusively military recruits, most of them male and aged under 30. Interventions involving strength training were also all conducted among male football players and with rather small sample sizes. Consequently the applicability of these findings to other age and sports groups is limited and should be tested in future studies.

The trials were divided into subgroups according to the similarity of the preventive measures. This was done even though the interventions were not identical in all respects, and the study designs and participants were decidedly heterogeneous.

Our goal was to gather information as reliable as possible by using data from randomised studies only. Inclusion of controlled trials or cohort studies might have weakened the quality of evidence, although in some reviews (e.g. reviews assessing effectiveness of neuromuscular training [16-17, 20]) inclusion of non-randomised trials has still given results similar to ours.

Future studies should focus on time and resource-efficient preventive methods. The mechanisms behind effective methods and the most beneficial elements of preventive interventions need to be ascertained. Sports specific preventive training programmes should be developed and tested properly, not only in the prevention of acute but also of stress injuries, because specified training intended to increase neuromuscular control and sports specific skills probably has multiple advantages. Finally, wide-scale implementation studies are needed to find out how interventions proven to be effective in smaller controlled intervention studies work in real life.

5 CONCLUSIONS

This meta-analysis takes into account all randomised controlled intervention trials intended to prevent sports injuries. It provides information on what has been studied and what needs to be studied more, and also on which methods are truly preventive versus those which have no preventive effect in light of the evidence from RCTs.

The significance of the current findings is that sports injuries can be prevented at least to a certain extent by using injury and sports specific methods, and by taking such preventive actions in practice may yield major benefits. Because sports injuries are detrimental to an athlete's career and health, and incur major costs for society, it is essential to promote evidence-based preventive methods.

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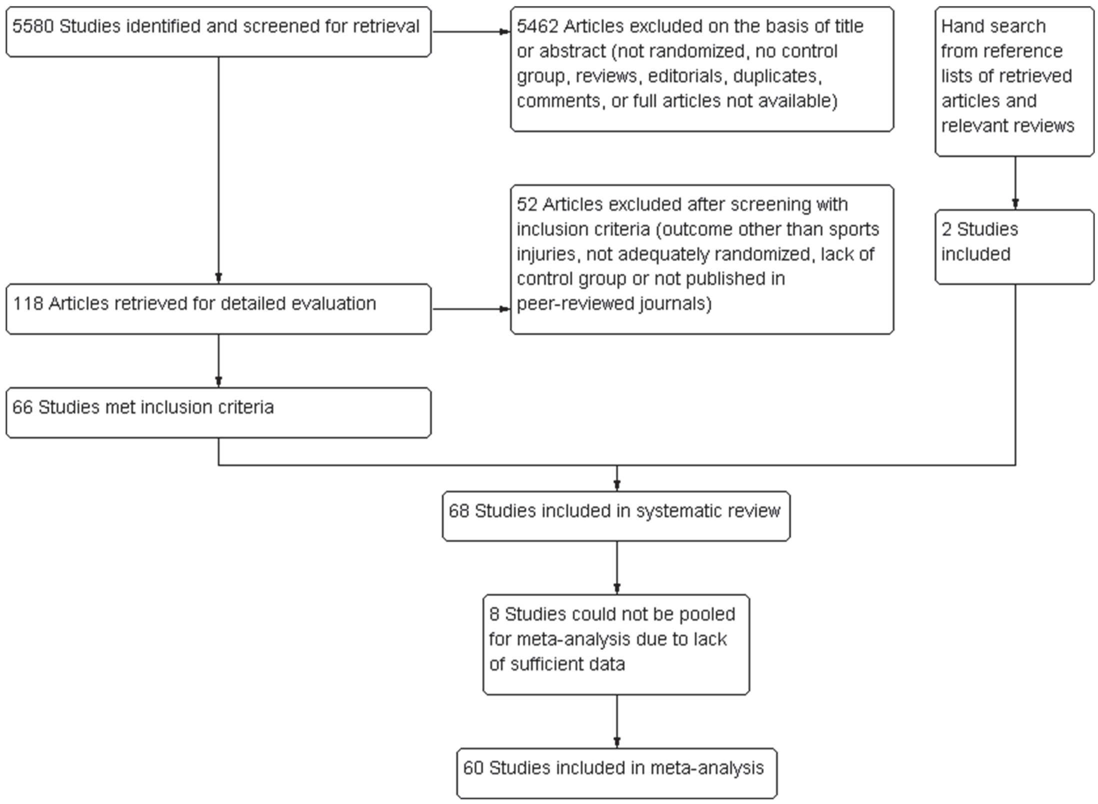

Fig. 1 Literature search flow chart

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Odds Ratio IV, Random, 95% CI
1.1.1 Insoles						
Finestone et al. 1999	16	126	19	71	12.0%	0.40 [0.19, 0.84]
Franklyn-Mill et al. 2011	21	200	61	200	14.0%	0.27 [0.16, 0.46]
Mattila et al. 2011	34	73	56	147	13.8%	1.42 [0.80, 2.50]
Milgrom et al. 1985	33	113	70	152	14.3%	0.48 [0.29, 0.81]
Schwellnus et al. 1990	49	237	317	1151	15.9%	0.69 [0.49, 0.96]
Smith et al. 1985	6	23	15	24	7.7%	0.21 [0.06, 0.74]
Smith et al. 1985b	3	21	15	24	6.3%	0.10 [0.02, 0.44]
Withnall et al. 2006	149	805	72	401	16.1%	1.04 [0.76, 1.42]
Subtotal (95% CI)		**1598**		**2170**	**100.0%**	**0.51 [0.32, 0.81]**
Total events	311		625			
Heterogeneity: Tau² = 0.32; Chi² = 38.41, df = 7 (P < 0.00001); I² = 82%						
Test for overall effect: Z = 2.83 (P = 0.005)						
Total (95% CI)		**1598**		**2170**	**100.0%**	**0.51 [0.32, 0.81]**
Total events	311		625			
Heterogeneity: Tau² = 0.32; Chi² = 38.41, df = 7 (P < 0.00001); I² = 82%						
Test for overall effect: Z = 2.83 (P = 0.005)						
Test for subgroup differences: Not applicable						

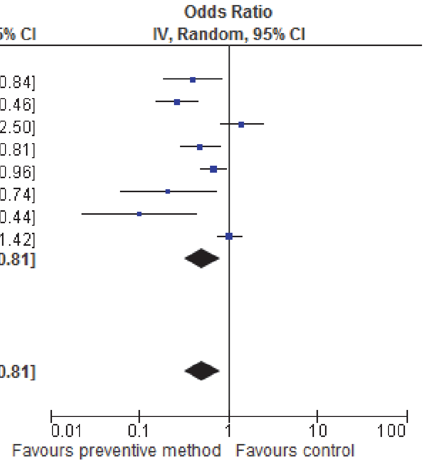

Fig. 2 Insoles vs. control. OR, pooled OR, 95% confidence intervals, and test of heterogeneity

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
2.1.1 Ankle supports						
Amoroso et al. 1998	5	369	10	376	4.3%	0.50 [0.17, 1.49]
McGuine et al. 2011	26	740	75	720	19.0%	0.31 [0.20, 0.50]
McGuine et al. 2012	27	993	68	1088	19.2%	0.42 [0.27, 0.66]
Mohammadi 2007	2	20	8	20	1.8%	0.17 [0.03, 0.92]
Sitler et al. 1994	11	789	35	812	9.9%	0.31 [0.16, 0.62]
Surve et al. 1994	48	244	75	260	22.0%	0.60 [0.40, 0.91]
Tropp et al. 1985	2	60	30	171	2.4%	0.16 [0.04, 0.70]
Subtotal (95% CI)		**3215**		**3447**	**78.5%**	**0.40 [0.30, 0.53]**
Total events	121		301			
Heterogeneity: Tau² = 0.04; Chi² = 8.07, df = 6 (P = 0.23); I² = 26%						
Test for overall effect: Z = 6.33 (P < 0.00001)						
2.1.2 Wrist supports						
Machold et al. 2002	1	342	9	379	1.2%	0.12 [0.02, 0.96]
Rønning et al. 2001	8	2515	29	2514	7.7%	0.27 [0.12, 0.60]
Subtotal (95% CI)		**2857**		**2893**	**9.0%**	**0.25 [0.12, 0.51]**
Total events	9		38			
Heterogeneity: Tau² = 0.00; Chi² = 0.53, df = 1 (P = 0.47); I² = 0%						
Test for overall effect: Z = 3.74 (P = 0.0002)						
2.1.3 Knee supports						
Sitler et al. 1990	16	691	37	705	12.5%	0.43 [0.24, 0.78]
Subtotal (95% CI)		**691**		**705**	**12.5%**	**0.43 [0.24, 0.78]**
Total events	16		37			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.79 (P = 0.005)						
Total (95% CI)		**6763**		**7045**	**100.0%**	**0.39 [0.31, 0.49]**
Total events	146		376			
Heterogeneity: Tau² = 0.02; Chi² = 10.37, df = 9 (P = 0.32); I² = 13%						
Test for overall effect: Z = 8.09 (P < 0.00001)						
Test for subgroup differences: Chi² = 1.55, df = 2 (P = 0.46), I² = 0%						

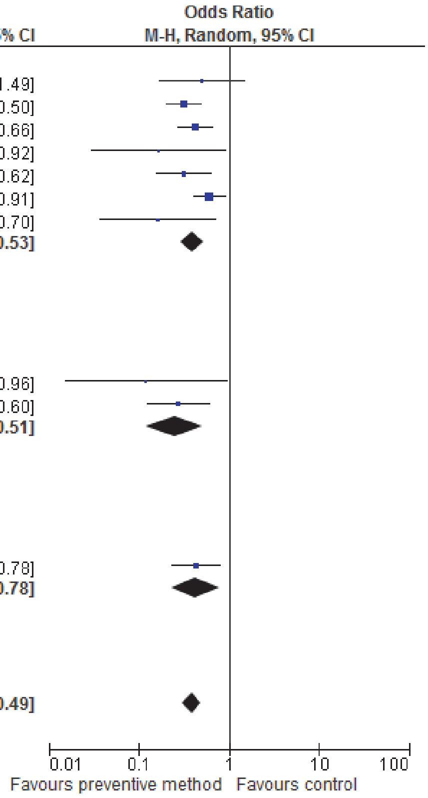

Fig. 3 External joint supports vs. control. OR, pooled OR, 95% confidence intervals, and test of heterogeneity

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
3.1.1 Balance board training						
Emery et al. 2005	2	66	10	61	1.0%	0.16 [0.03, 0.76]
Hupperets et al. 2009	56	256	89	266	3.8%	0.56 [0.38, 0.82]
Mohammadi 2007	1	20	8	20	0.6%	0.08 [0.01, 0.71]
Söderman et al. 2000	23	62	25	78	2.7%	1.25 [0.62, 2.52]
Tropp et al. 1985b	7	142	30	171	2.2%	0.24 [0.10, 0.57]
Verhagen et al. 2004	29	392	41	340	3.4%	0.58 [0.35, 0.96]
Wester et al. 1996	6	24	13	24	1.4%	0.28 [0.08, 0.96]
Subtotal (95% CI)		**962**		**960**	**15.0%**	**0.45 [0.28, 0.73]**
Total events	124		216			
Heterogeneity: Tau^2 = 0.22; Chi^2 = 15.37, df = 6 (P = 0.02); I^2 = 61%						
Test for overall effect: Z = 3.20 (P = 0.001)						
3.1.2 Multi-intervention with balance board training						
Eils et al. 2010	7	81	21	91	2.1%	0.32 [0.13, 0.79]
Emery & Meeuwisse 2010	48	380	70	364	3.7%	0.61 [0.41, 0.91]
Emery et al. 2007	130	494	141	426	4.1%	0.72 [0.54, 0.96]
McGuine & Keene 2006	23	373	39	392	3.2%	0.59 [0.35, 1.02]
Pasanen et al. 2008	20	256	40	201	3.1%	0.34 [0.19, 0.60]
Wedderkopp et al 1999	11	111	45	126	2.6%	0.20 [0.10, 0.41]
Wedderkopp et al. 2003	6	77	16	86	1.9%	0.37 [0.14, 1.00]
Subtotal (95% CI)		**1772**		**1686**	**20.7%**	**0.46 [0.32, 0.64]**
Total events	245		372			
Heterogeneity: Tau^2 = 0.12; Chi^2 = 16.27, df = 6 (P = 0.01); I^2 = 63%						
Test for overall effect: Z = 4.46 (P < 0.00001)						
3.1.3 Other multi-interventions						
Brushøj et al. 2008	108	507	91	513	4.0%	1.26 [0.92, 1.71]
Collard et al. 2010	100	1015	104	996	4.1%	0.94 [0.70, 1.25]
Ekstrand et al. 1983	23	90	62	90	2.8%	0.16 [0.08, 0.30]
Engebretsen et al. 2008	114	193	114	195	3.7%	1.03 [0.68, 1.54]
Heidt et al. 2000	6	42	87	258	2.1%	0.33 [0.13, 0.81]
Holme et al. 1999	2	29	11	38	1.0%	0.18 [0.04, 0.90]
Hägglund et al. 2007	10	90	23	79	2.3%	0.30 [0.13, 0.69]
Parkkari et al. 2011	114	501	120	467	4.1%	0.85 [0.63, 1.14]
van Mechelen et al. 1993	24	159	20	167	2.9%	1.31 [0.69, 2.47]
Subtotal (95% CI)		**2626**		**2803**	**27.1%**	**0.63 [0.42, 0.95]**
Total events	501		632			
Heterogeneity: Tau^2 = 0.28; Chi^2 = 49.37, df = 8 (P < 0.00001); I^2 = 84%						
Test for overall effect: Z = 2.21 (P = 0.03)						
3.1.4 Warm-up programs						
Gilchrist et al. 2008	2	583	10	852	1.0%	0.29 [0.06, 1.33]
LaBella et al. 2011	47	737	83	755	3.8%	0.55 [0.38, 0.80]
Longo et al. 2012	14	80	17	41	2.2%	0.30 [0.13, 0.70]
Olsen et al. 2005	46	958	76	879	3.8%	0.53 [0.37, 0.78]
Soligard et al. 2008	121	1055	143	837	4.2%	0.63 [0.48, 0.82]
Steffen et al. 2008	204	1073	192	947	4.3%	0.92 [0.74, 1.15]
van Beijsterveldt et al.	135	223	139	233	3.8%	1.04 [0.71, 1.51]
Waldén et al. 2012	7	2479	14	2085	2.1%	0.42 [0.17, 1.04]
Subtotal (95% CI)		**7188**		**6629**	**25.3%**	**0.64 [0.49, 0.83]**
Total events	576		674			
Heterogeneity: Tau^2 = 0.08; Chi^2 = 20.81, df = 7 (P = 0.004); I^2 = 66%						
Test for overall effect: Z = 3.39 (P = 0.0007)						
3.1.5 Strenght training						
Askling et al. 2003	3	15	10	15	0.9%	0.13 [0.02, 0.66]
Mohammadi 2007	4	20	8	20	1.2%	0.38 [0.09, 1.54]
Petersen et al. 2011	15	461	52	481	3.0%	0.28 [0.15, 0.50]
Subtotal (95% CI)		**496**		**516**	**5.1%**	**0.27 [0.16, 0.45]**
Total events	22		70			
Heterogeneity: Tau^2 = 0.00; Chi^2 = 1.04, df = 2 (P = 0.59); I^2 = 0%						
Test for overall effect: Z = 5.00 (P < 0.00001)						
3.1.6 Graded running program						
Bredeweg et al. 2012	26	171	32	191	3.1%	0.89 [0.51, 1.57]
Buist et al. 2008	52	250	48	236	3.6%	1.03 [0.66, 1.60]
Subtotal (95% CI)		**421**		**427**	**6.7%**	**0.97 [0.69, 1.38]**
Total events	78		80			
Heterogeneity: Tau^2 = 0.00; Chi^2 = 0.15, df = 1 (P = 0.69); I^2 = 0%						
Test for overall effect: Z = 0.15 (P = 0.88)						
Total (95% CI)		**13465**		**13021**	**100.0%**	**0.55 [0.46, 0.66]**
Total events	1546		2044			
Heterogeneity: Tau^2 = 0.17; Chi^2 = 138.26, df = 35 (P < 0.00001); I^2 = 75%						
Test for overall effect: Z = 6.60 (P < 0.00001)						
Test for subgroup differences: Chi^2 = 20.77, df = 5 (P = 0.0009), I^2 = 75.9%						

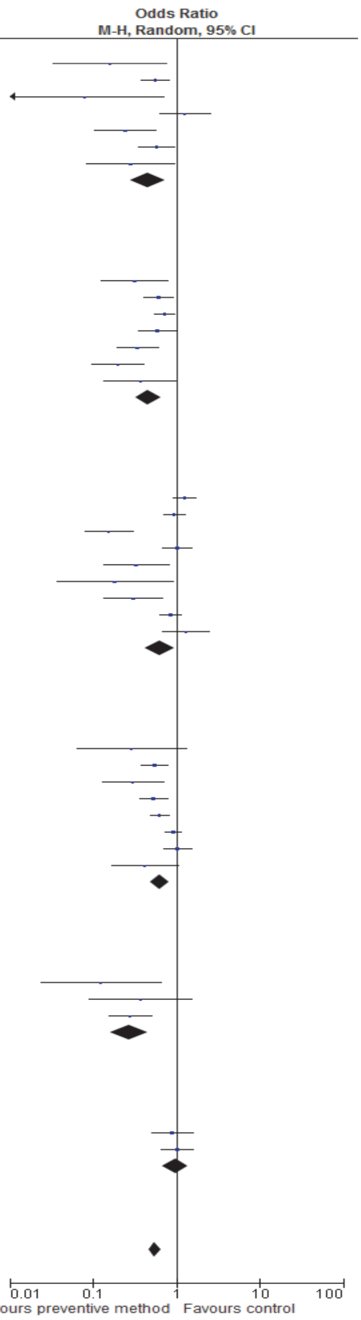

Fig. 4 Training programmes vs. control. OR, pooled OR, 95% confidence intervals, and test of heterogeneity

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Odds Ratio M-H, Fixed, 95% CI
4.1.1 Stretching						
Jamtvedt et al. 2010	339	1220	348	1157	62.4%	0.89 [0.75, 1.07]
Pope et al. 1998	23	451	25	432	5.9%	0.87 [0.49, 1.57]
Pope et al. 2000	158	735	175	803	31.8%	0.98 [0.77, 1.25]
Subtotal (95% CI)		**2406**		**2392**	**100.0%**	**0.92 [0.80, 1.06]**
Total events	520		548			
Heterogeneity: Chi² = 0.41, df = 2 (P = 0.82); I² = 0%						
Test for overall effect: Z = 1.15 (P = 0.25)						
Total (95% CI)		**2406**		**2392**	**100.0%**	**0.92 [0.80, 1.06]**
Total events	520		548			
Heterogeneity: Chi² = 0.41, df = 2 (P = 0.82); I² = 0%						
Test for overall effect: Z = 1.15 (P = 0.25)						
Test for subgroup differences: Not applicable						

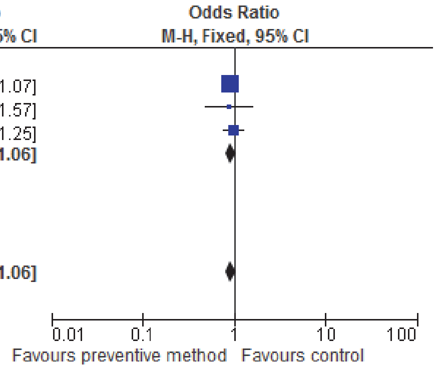

Fig. 5 Stretching vs. control. OR, pooled OR, 95% confidence intervals, and test of heterogeneity

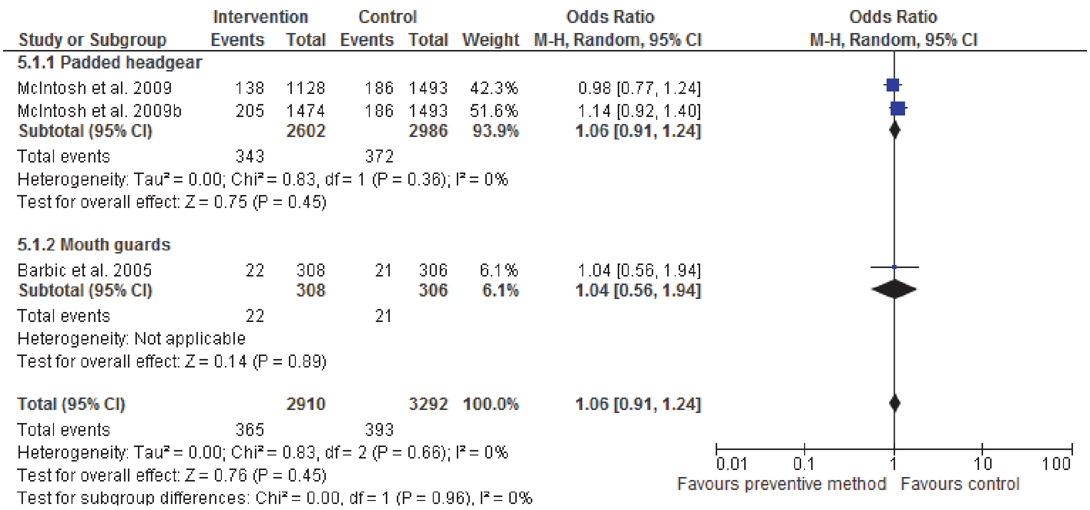

Fig. 6 Protective head equipment vs. control. OR, pooled OR, 95% confidence intervals, and test of heterogeneity

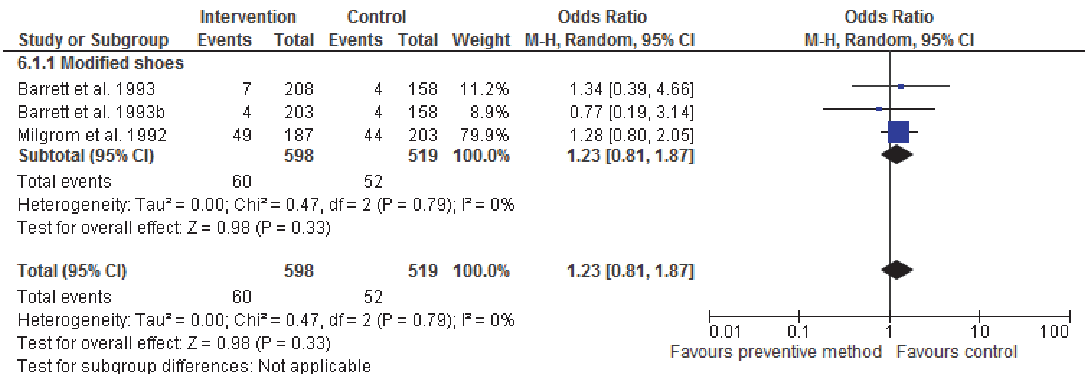

Fig. 7 Modified shoes vs. control. OR, pooled OR, 95% confidence intervals, and test of heterogeneity

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
7.1.1 Videos						
Arnason et al. 2005	94	127	96	144	41.7%	1.42 [0.84, 2.41]
Cusimano et al. 2013	2	35	4	34	11.4%	0.45 [0.08, 2.66]
Jørgensen et al. 1998	39	243	119	520	46.9%	0.64 [0.43, 0.96]
Subtotal (95% CI)		**405**		**698**	**100.0%**	**0.86 [0.44, 1.68]**
Total events	135		219			
Heterogeneity: Tau² = 0.21; Chi² = 6.03, df = 2 (P = 0.05); I² = 67%						
Test for overall effect: Z = 0.44 (P = 0.66)						
Total (95% CI)		**405**		**698**	**100.0%**	**0.86 [0.44, 1.68]**
Total events	135		219			
Heterogeneity: Tau² = 0.21; Chi² = 6.03, df = 2 (P = 0.05); I² = 67%						
Test for overall effect: Z = 0.44 (P = 0.66)						
Test for subgroup differences: Not applicable						

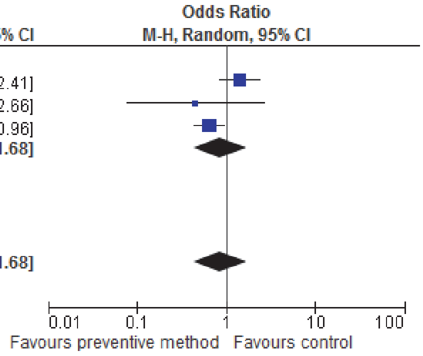

Fig. 8 Injury prevention videos vs. control. OR, pooled OR, 95% confidence intervals, and test of heterogeneity

Electronic Supplementary Material Table S1: Characteristics of included trials

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
			Insoles					
Finestone et al. 1999	Biomechanical shoe orthoses (custom)	Infantry recruits (100%)	17-27	260/144	14 wk	Lower extremity stress fractures	OR, 0.40 [0.19, 0.84][c]	4/12
Finestone et al. 2004	(1) Soft orthoses (custom) (2) Soft orthoses (prefabricated) (3) Semirigid biomechanical orthoses (custom) (4) Semirigid orthoses (prefabricated)	Infantry recruits (100%)	18-20	(1) 227 (2) 224 (3) 215 (4) 208	14 wk	Lower extremity overuse injuries	NC; no group differences observed	5/12
Franklyn-Miller et al. 2011	Foot orthoses	Military officer trainees (65%)	25 (mean)	200/200	7 wk	Overuse lower limb injuries	OR, 0.27 [0.16, 0.46][c]	5/12
Larsen et al. 2002	Biomechanical shoe orthoses (custom)	Military conscripts (99,3%)	18-24	77/69	3 mo	Back and lower extremity problems	RR, 0.70 [0.50-1.10] (NC)	7/12
Mattila et al. 2011	Orthotic insoles	Military conscripts (100%)	18-29	73/147	6 mo	Lower limb overuse injury	OR, 1.42 [0.80, 2.50][c]	9/12
Milgrom et al. 1985	Shock-absorbing orthotic devices (prefabricated)	Military recruits (100%)	NR	143/152	14 wk	Lower extremity stress fractures	OR, 0.48 [0.29, 0.81][c]	3/12
Schwellnus et al. 1990	Neoprene insoles (prefabricated)	Military recruits (NR)	17-25	250/1261	9 wk	Lower extremity overuse injuries	OR, 0.69 [0.49, 0.96][b]	3/12
Smith et al. 1985	(1) Poron insoles (prefabricated) (2) Spenco insoles (prefabricated) (3) Control	Coast guard recruits (NR)	17-25	(1) 30 (2) 30 (3) 30	8 wk	Lower extremity injuries	(1) vs (3) OR, 0.21 [0.06, 0.74][c] (2) vs (3) OR, 0.10 [0.02, 0.44][c]	2/12
Withnall et al. 2006	(1) Shock absorbing insole (Sorbothane SAI) (2) Shock absorbing insole (Poron SAI) (3) Non-shock absorbing insole (control)	Military recruits (77.8%)	16-35	(1) 421 (2) 383 (3) 401	8 mo	Any lower limb injury	(1) and (2) vs (3) OR,1.04 [0.76, 1.42][c]	6/12

Table S1 cont'd.

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
			External Joint Supports					
Amoroso et al. 1998	Outside-the.boot braces	Military paratrooper students (100%)	>18	369/376	1 wk	Ankle injuries	OR, 0.50 [0.17, 1.49][c]	6/12
McGuine et al. 2011[e,f]	Lace-up ankle braces	High-school basketball players (49.6%)	16 (mean)	740/720	1 Playing season	Acute ankle injuries	OR, 0.31 [0.20, 0.50][c]	3/12
McGuine et al. 2012[e,f]	Lace-up ankle braces	High-school American football players (NR)	NR	993/1088	1 Playing season	Acute ankle injuries	OR, 0.42 [0.27,0.66][b]	3/12
Machold et al. 2002	Wrist protectors	Students (60%)	14.8 (mean)	342/379	1 wk	Wrist injuries	OR, 0.12 [0.02, 0.96][c]	5/12
Mohammadi 2007	Sport-Stirrup ankle orthoses	Football players (100%)	24.6 (mean)	20/20	1 Playing season	Ankle sprain recurrences	OR, 0.17 [0.03, 0.92][c]	3/12
Rønning et al. 2001	Wrist protectors	Snowboarders (64.2%)	10-68	2515/2514	3 mo	Wrist injuries	OR, 0.27 [0.12, 0.60][c]	7/12
Sitler et al. 1990	Prophylactic knee braces	Military academy cadets (NR)	18-21	691/705	2 y	Knee injuries	OR, 0.43 [0.24, 0.78][c]	4/12
Sitler et al. 1994	Semirigid ankle stabilizers	Military academy cadets (NR)	18-21	789/812	2 y	Ankle injuries	OR, 0.31 [0.16, 0.62][c]	3/12
Surve et al. 1994	Sport-Stirrup ankle orthoses	Senior football players (100%)	NR	244/260	1 Playing season	Ankle sprains	OR, 0.60 [0.40, 0.91][c]	2/12
Tropp et al. 1985[e]	Ankle orthoses	Senior football players (100%)	NR	124/180	6 mo	Ankle sprains	OR, 0.16 [0.04, 0.70][c]	3/12
			Training programmes: Balance Board Training					
Emery et al. 2005[e,f]	Home-based balance training programme	Physical education students (50%)	14-19	66/61	6 mo	Sports injuries	OR, 0.16 [0.03, 0.76][c]	6/12
Hupperets et al. 2009	Home based proprioceptive training programme	Athletes with previous ankle sprain (52.5%)	12-70	256/266	1 y	Recurrence of ankle sprain	OR, 0.56 [0.38, 0.82][c]	7/12
Mohammadi 2007	Proprioceptive ankle disk training	Football players (100%)	24.6 (mean)	20/20	1 Playing season	Ankle sprain recurrences	OR, 0.08 [0.01, 0.71][c]	3/12
Söderman et al. 2000[e]	Balance-board training programme	Football players (0%)	15-25	121/100	7 mo	Lower extremity injuries	OR, 1.25 [0.62, 2.52][c]	3/12
Tropp et al. 1985[e]	Ankle disk training	Senior football players (100%)	NR	144/180	6 mo	Ankle sprains	OR, 0.24 [0.10, 0.57][c]	3/12
Verhagen et al. 2004	Balance board training programme	Volleyball players (42,9%)	21-27	641/486	36 wk	Ankle injuries	OR, 0.58 [0.35,0.96][b]	4/12
Wester et al. 1996	Wobble board training	Athletes with primary ankle sprain (60,4%)	25 (mean)	24/24	12 wk	Recurrent ankle sprain	OR, 0.28 [0.08, 0.96][c]	2/12

Table S1 cont'd.

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Training Programmes: Multi-Intervention With Balance Board								
Eils et al. 2010	Multistation proprioceptive exercise programme	Basketball players (59%)	14-43	96/102	1 Playing season	Ankle injuries	OR, 0.32 [0.13, 0.79][b]	4/12
Emery & Meeuwisse 2010[e,f]	Neuromuscular training programme and home-based balance training program	Indoor football players (42%)	13-18	481/537	1 y	All injuries	OR, 0.61 [0.41, 0.91][c]	5/12
Emery et al. 2007[e,f]	Balance training programme	High-school basketball players (50.4%)	12-18	494/426	1 y	All injuries	OR, 0.72 [0.54, 0.96][b]	5/12
McGuine & Keene 2006	Balance training programme	High-school football and basketball players (31.6%)	16.5 (mean)	373/392	1 Playing season	Ankle sprains	OR, 0.59 [0.35, 1.02][c]	5/12
Pasanen et al. 2008[e,f]	Neuromuscular training programme	Floorball players (0%)	24 (mean)	256/201	6 mo	Acute non-contact injuries of the legs	OR, 0.34 [0.19, 0.60][c]	8/12
Wedderkopp et al. 2003[e,f]	Ankle disk and functional strength training	Handball players (0%)	14-16	77/86	9 mo	Sports injuries	OR, 0.37 [0.14, 1.00][b]	4/12
Wedderkopp et al. 1999[e]	Ankle disk and functional warm-up training	Handball players (0%)	16-18	111/126	10 mo	Sports injuries	OR, 0.20 [0.10, 0.41][c]	2/12
Training Programmes: Other Multi-Interventions								
Brushøj et al. 2008[g]	Preventive training programme	Military soldiers (100%)	19-26	507/513	12 wk	Lower extremity injuries	OR, 1.26 [0.92, 1.71][c]	7/12
Collard et al. 2010[e,f]	School-based physical activity injury prevention programme	Children (44.7%)	10-12	1117/1091	8 mo	Sports injuries	OR, 0.94 [0.70, 1.25][c]	5/12
Ekstrand et al. 1983[e]	Prophylactic programme	Senior football players (100%)	17-37	90/90	6 mo	Sports injuries	OR, 0.16 [0.08, 0.30][b]	2/12
Engebretsen et al. 2008	(1) Targeted exercise programme, high risk players (intervention) (2) High-risk players (control) (3) Low-risk players (control)	Football players (100%)	NR	(1) 193 (2) 195 (3) 120	10 wk	Ankle, knee, hamstring and groin injuries	(1) vs (2) OR, 1.03 [0.68, 1.54][c]	4/12
Heidt et al. 2000	Preseason training programme	Football players (100%)	14-18	42/258	12 mo	Sports injuries	OR, 0.33 [0.13, 0.81][c]	3/12
Holme et al. 1999	Rehabilitation programme	Recreational athletes (62%)	21-32	46/46	12 mo	Ankle sprain re-injuries	OR, 0.18 [0.04, 0.90][c]	3/12
Hägglund et al. 2007[e]	Coach-controlled rehabilitation programme	Amateur football players (100%)	15-46	282/300	1 Playing season	All injuries Recurrence of injuries	OR, 0.30 [0.13, 0.69][c]	6/12
Parkkari et al. 2011[e]	Neuromuscular training programme with injury prevention counseling	Military conscripts (100%)	18-28	501/467	6 mo	Acute lower- and upper-limb injury	OR, 0.85 [0.63, 1.14][c]	7/12
van Mechelen et al. 1993	Warm-up, cooldown, and stretching programme	Recreational runners (100%)	NR	210/211	16 wk	Lower extremity and back injuries	OR, 1.31 [0.69, 2.47][c]	2/12

Table S1 cont'd.

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Training Programmes: Warm-up Programs								
Gilchrist et al. 2008[e]	Warm-up program to enhance neuromuscular and proprioceptive control	Football players (0%)	20 (mean)	583/852	1 Playing season	Anterior cruciate ligament injuries	OR, 0.29 [0.06, 1.33][b]	4/12
LaBella et al. 2011[e,f]	Neuromuscular warm-up programme	High-school football and basketball players (0%)	16 (mean)	760/798	1 Playing season	Lower limb injuries	OR, 0.55 [0.38, 0.80][c]	6/12
Longo et al. 2012[e]	The FIFA 11+ warm-up programme	Basketball players (100%)	14 (mean)	80/41	9 mo	All injuries	OR, 0.30 [0.13, 0.70][b]	8/12
Olsen et al. 2005[e,f]	Structured warm-up programme	Handball players (13.7%)	15-17	958/879	8 mo	Ankle and knee injuries	OR, 0.53 [0.37, 0.78][c]	7/12
Soligard et al. 2008[e,f]	Comprehensive warm-up programme	Football players (0%)	13-17	1055/837	8 mo	Lower extremity injuries	OR, 0.63 [0.48, 0.82][c]	5/12
Steffen et al. 2008[e,f]	Training program focusing on core stability, balance, dynamic stabilization and eccentric hamstring strength	Football players (0%)	13-17	1091/1001	8 mo	All injuries	OR, 0.92 [0.74, 1.15][c]	6/12
van Beijsterveldt et al. 2012[e]	'The 11' Injury prevention programme	Amateur football players (100%)	18-40	223/233	9 mo	All injuries	OR, 1.04 [0.71, 1.51][c]	5/12
Waldén et al. 2012[e]	Neuromuscular warm-up programme	Football players (0%)	12-17	2479/2085	1 Playing season	Anterior cruciate ligament injuries	OR, 0.42 [0.17, 1.04][c]	8/12
Training Programmes: Strength Training								
Askling et al. 2003	Eccentric strength training for the hamstring muscles	Elite football players (100%)	25 (mean)	15/15	10 wk	Hamstring injuries	OR, 0.13 [0.02, 0.66][c]	6/12
Gabbe et al. 2006	Eccentric exercise programme	Amateur Australian football players (100%)	17-36	114/106	12 wk	Hamstring injuries	RR (NC), 1.2 [0.5, 2.8]	5/12
Mohammadi 2007	Specific strength training of evertor muscles	Football players (100%)	24,6 (mean)	20/20	1 Playing season	Ankle sprain recurrences	OR, 0.38 [0.09, 1.54][c]	3/12
Petersen et al. 2011[e,f]	Eccentric training programme	Football players (100%)	23 (mean)	461/481	10 wk	Acute hamstring injuries	OR, 0.28 [0.15, 0.50][c]	7/12
Training Programmes: Graded Running Programmes								
Bredeweg et al. 2012	Preconditioning programme	Novice runners (34,5%)	38.1 (mean)	171/191	13 wk	Running-related injuries	OR, 0.89 [0.51, 1.57][c]	6/12
Buist et al. 2008	Graded training programme	Novice runners (42.5%)	39.8 (mean)	264/268	13 wk	Running-related injuries	OR, 1.03 [0.66, 1.60][c]	4/12

Table S1 cont'd.

Source	Intervention	Participants (% male)	Age Range, y	Participants, Intervention/ Control, No.	Duration	Outcome	OR or RR (95% CI)	Quality Score
Stretching								
Bello et al. 2011	Rhytmic stabilisation (RS) streching technique	Indoor football players (NR)	18-27	7/7	4 mo	Lower limb injuries	NC; no group differences observed	2/12
Jamtvedt et al. 2010	Stretching programme	Physically active adults (36.4%)	40 (mean)	1220/1157	12 wk	Any injury to the lower limb or back	OR, 0.89 [0.75, 1.07][c]	4/12
Pope et al. 1998[e,g]	Preexercise calf muscle stretching	Army recruits (100%)	17-35	594/544	12 wk	Lower extremity injuries	OR, 0.87 [0.49, 1.57][c]	4/12
Pope et al. 2000[e,g]	Lower extremity stretching programme	Army recruits (100%)	17-35	735/803	12 wk	Lower extremity injuries	OR, 0.98 [0.77, 1.25][c]	5/12
Protective Head Equipment								
Barbic et al. 2005[e,f]	Type II (boil-and-bite) mouth guard	University students (81%)	20.9 (mean)	322/324	3 mo	Concussions	OR, 1.04 [0.56, 1.94][c]	4/12
Finch et al. 2005[e,f]	Custom-made mouth guard	Australian football players (100%)	15-31	190/111	1 Playing season	Head/ Orofacial injuries	RR (NC), 0.56 [0.32-0.97]	4/12
McIntosh et al. 2009[e,f]	(1) Standard headgear (2) Modified padded headgear (3) Control	Rugby union players (100%)	<20	(1) 1128 (2) 1474 (3) 1493	2 Playing seasons	Head injury or concussion	(1) vs (3) OR, 0.98 [0.77, 1.24][b] (2) vs (3) OR, 1.14 [0.92, 1.40][b]	3/12
Modified Shoes								
Barrett et al. 1993	(1) High-top shoes (2) High-top shoes with air chambers (3) Low-top shoes	College basketball players (91.7%)	20.6 (mean)	(1) 227 (2) 212 (3) 183	2 mo	Ankle sprains	(1) vs (3) OR, 1.34 [0.39, 4.66][c] (2) vs (3) OR, 0.77 [0.19, 3.14][c]	4/12
Finestone et al. 1992	Modified basketball shoes	Infantry recruits (100%)	18-20	187/203	14 wk	Lower extremity overuse injuries	NC; no group differences observed	2/12
Kinchington et al. 2011	Tailored footwear programme	Professional rugby players (100%)	24 (mean)	32/27	30 wk	Lower limb injuries	NC; result favors intervention	3/12
Milgrom et al. 1992	Modified basketball shoes	Infantry recruits (100%)	NR	187/203	14 wk	Lower extremity stress fractures	OR, 1.28 [0.80, 2.05][c]	2/12
Videos								
Arnason et al. 2005[d]	Video-based awareness programme	Football players (100%)	NR	127/144	5 mo	Sports injuries	OR, 1.42 [0.84, 2.41][b]	3/12
Cusimano et al. 2013	Ski and snowboard injury prevention program	Students (NR)	11-12	35/34	NR	All injuries	OR, 0.45 [0.08, 2.66][c]	6/12
Jørgensen et al. 1998	Instructional ski video	Downhill skiers (58%)	5-61	243/520	1 wk	Sports injuries	OR, 0.64 [0.43, 0.96][c]	3/12
Other Interventions								
Lappe et al. 2008	Calcium and vitamin D supplementation	Navy recruits (0%)	17-35	2626/2575	8 wk	Stress fractures	OR, 0.80 [0.67, 0.97][b]	9/12

Table S1 cont'd.

Abbreviations: CI, confidence interval; NC, not calculated; NR, not reported; OR, odds ratio; RR, risk ratio.

[a] Comparison is made with a control group that has not participated in any intervention (except for Finestone et al., Barrett et al. and Bello et al.).

[b] Calculated by using the number of injured individuals in the intervention vs control groups.

[c] Calculated by using the number of injuries in the intervention vs control groups.

[d] Calculated by using detailed information received from the authors.

[e] Cluster randomised.

[f] Cluster randomisation was taken into account in the analyses of the original report.

[g] Quasi-randomised.

Electronic Supplementary Material Table S2: Methodological quality assessment of included trials

Trial	A1	B2	C3	C4	C5	D6	D7	E8	F9	F10	F11	F12	TOT
Amoroso et al. 1998	YES	US	US	US	YES	NO	US	YES	YES	US	YES	YES	6
Arnason et al. 2005	US	US	US	US	US	YES	NO	YES	US	US	US	YES	3
Askling et al. 2003	US	US	US	US	YES	YES	US	YES	YES	US	YES	YES	6
Barbic et al. 2005	US	US	NO	NO	NO	NO	NO	YES	YES	US	NO	YES	3
Barrett et al. 1993	YES	US	US	US	US	YES	US	YES	US	US	US	YES	4
Bello et al. 2011	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Bredeweg et al. 2012	YES	US	US	US	US	YES	YES	YES	YES	US	NO	YES	6
Brushoj et al. 2008	NO	YES	YES	US	YES	NO	US	YES	YES	US	YES	YES	7
Buist et al. 2008	YES	US	US	US	US	YES	YES	YES	NO	US	NO	US	4
Collard et al. 2010	YES	US	NO	NO	NO	YES	YES	YES	NO	US	US	YES	5
Cusimano et al. 2013	YES	US	NO	NO	NO	YES	YES	YES	US	US	YES	YES	6
Eils et al. 2010	YES	US	US	US	US	YES	US	YES	US	US	US	YES	4
Ekstrand et al. 1983	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Emery et al. 2005	YES	US	US	US	US	YES	YES	YES	YES	US	US	YES	6
Emery & Meeuwisse 2010	US	US	YES	US	YES	NO	YES	YES	NO	US	US	YES	5
Emery et al. 2007	YES	US	US	US	YES	US	US	YES	YES	US	NO	YES	5
Engebretsen et al. 2008	US	US	US	US	US	YES	YES	YES	US	NO	NO	YES	4
Finch et al. 2005	US	US	NO	NO	NO	YES	YES	YES	US	NO	US	YES	4
Finestone et al. 1992	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Finestone et al. 1999	YES	US	US	US	US	NO	NO	YES	US	US	YES	YES	4
Finestone et al. 2004	YES	US	YES	NO	NO	NO	US	YES	US	US	YES	YES	5
Franklyn-Miller et al. 2011	YES	US	NO	NO	NO	YES	YES	YES	US	US	US	YES	5
Gabbe et al. 2006	YES	NO	US	US	NO	US	YES	YES	YES	US	NO	YES	5
Gilchrist et al. 2008	US	US	US	US	US	NO	NO	YES	YES	US	YES	YES	4
Heidt et al. 2000	US	US	US	US	YES	US	US	YES	US	US	US	YES	3
Holme et al. 1999	YES	US	US	US	US	NO	US	YES	NO	US	US	YES	3
Hupperets et al. 2009	US	YES	US	US	YES	YES	YES	YES	YES	NO	NO	YES	7
Hägglund et al. 2007	US	YES	NO	NO	YES	YES	YES	YES	US	US	NO	YES	6
Jamtvedt et al. 2010	YES	US	NO	US	US	US	YES	YES	US	US	NO	YES	4
Jørgensen et al. 1998	US	US	US	US	US	US	US	YES	YES	US	US	YES	3
Kinchington et al. 2011	US	US	US	US	US	YES	NO	YES	US	NO	US	YES	3
LaBella et al. 2011	YES	YES	US	NO	NO	YES	YES	YES	NO	US	US	YES	6
Lappe et al. 2008	YES	YES	YES	YES	YES	NO	YES	YES	YES	US	US	YES	9
Larsen et al. 2002	YES	US	US	YES	US	YES	YES	YES	US	US	YES	YES	7
Longo et al. 2012	YES	YES	NO	NO	YES	YES	YES	YES	NO	US	YES	YES	8
Machold et al. 2002	YES	US	US	US	US	US	YES	YES	US	US	YES	YES	5
Mattila et al. 2011	YES	US	US	YES	YES	YES	YES	YES	YES	US	YES	YES	9
McGuine & Keene 2006	US	YES	NO	NO	US	NO	YES	YES	YES	US	US	YES	5
McGuine et al. 2011	US	US	NO	NO	NO	YES	YES	US	US	US	US	YES	3
McGuine et al. 2012	US	US	NO	NO	NO	YES	YES	US	US	US	US	YES	3
McIntosh et al. 2009	US	US	US	US	US	YES	YES	YES	US	US	NO	US	3
Milgrom et al. 1985	US	US	US	US	US	YES	US	YES	US	US	US	YES	3
Milgrom et al. 1992	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Mohammadi 2007	US	US	US	US	US	YES	US	YES	US	US	NO	YES	3
Olsen et al. 2005	US	YES	US	US	YES	YES	YES	YES	US	NO	YES	YES	7
Parkkari et al. 2011	YES	YES	NO	NO	YES	NO	YES	YES	NO	US	YES	YES	7
Pasanen et al. 2008	YES	YES	NO	NO	YES	YES	YES	YES	YES	US	NO	YES	8
Petersen et al. 2011	YES	YES	NO	NO	NO	YES	US	YES	YES	US	YES	YES	7
Pope et al. 1998	US	YES	YES	US	US	NO	US	YES	US	US	US	YES	4
Pope et al. 2000	US	YES	US	US	YES	NO	YES	YES	US	US	US	YES	5
Rønning et al. 2001	US	US	US	US	YES	YES	YES	YES	YES	US	YES	YES	7
Schwellnus et al. 1990	US	US	US	US	US	US	US	YES	US	US	YES	YES	3
Sitler et al. 1990	YES	US	US	US	US	US	US	YES	US	US	YES	YES	4
Sitler et al. 1994	US	US	US	US	US	US	US	YES	US	US	YES	YES	3
Smith et al. 1985	US	US	US	US	US	NO	US	YES	US	US	US	YES	2
Soligard et al. 2008	US	YES	NO	NO	YES	NO	YES	YES	US	US	US	YES	5
Steffen et al. 2008	US	YES	NO	NO	YES	YES	YES	YES	US	US	NO	YES	6
Surve et al. 1994	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Söderman et al. 2000	US	US	US	US	US	NO	NO	YES	YES	US	NO	YES	3
Tropp et al. 1985	US	US	US	US	US	YES	US	YES	US	US	US	YES	3
van Beijsterveldt et al. 2012	YES	US	NO	NO	NO	YES	US	YES	NO	US	YES	YES	5
van Mechelen et al. 1993	US	US	US	US	US	NO	US	YES	US	US	NO	YES	2
Verhagen et al. 2004	US	US	US	US	YES	NO	US	YES	YES	US	US	YES	4
Walden et al. 2012	YES	YES	NO	NO	YES	YES	YES	YES	YES	US	US	YES	8
Wedderkopp et al. 1999	US	US	US	US	US	US	US	YES	US	US	US	YES	2
Wedderkopp et al. 2003	US	US	US	US	NO	YES	YES	YES	US	US	US	YES	4
Wester et al. 1996	YES	US	US	US	US	NO	US	YES	US	US	US	NO	2
Whitnall et al. 2006	YES	YES	NO	NO	NO	YES	YES	YES	US	US	US	YES	6

Table S2 cont'd.

Abbreviations:
A1, adequate randomisation (yes = random assignment was performed by using a computer-generated random sequence, pre-ordered sealed envelopes, or another clearly described and acceptable random method).
B2, concealed allocation (yes = assignment was generated by an independent person not responsible for determining the eligibility of the study participants).
C3, blinding of the study participants (yes = the index and control groups were indistinguishable for the study participants).
C4, blinding of the care providers (yes = the index and control groups were indistinguishable for the care providers (eg. physicians, physiotherapists, trainers) involved in the study).
C5, blinding of the outcome assessors (yes = physicians, physiotherapists, radiologists, researchers, and other staff who evaluated the injuries were blinded regarding group assignment).
D6, described and acceptable drop-out rate (yes = drop-out rate was < 20% for short-term follow-up [0-3 months] or < 30% for long-term follow-up [over 3 months] and reasons for drop-out was given).
D7, intention-to-treat analysis (yes = all randomised participants were analysed in the group they were allocated to by randomisation irrespective of non-compliance and co-interventions).
E8, reports of the study free of suggestion of selective outcome reporting (yes = published report includes enough information and all the results from outcomes have been adequately reported).
F9, similarity between groups at baseline (yes = study groups were similar at baseline regarding demographic factors and other important prognostic factors).
F10, avoided or similar co-interventions (yes = there were no co-interventions or they were similar between the index and control groups).
F11, acceptable compliance (yes = compliance was regularly checked or otherwise supervised and it was more than 70% in every study group).
F12, similar timing of the outcome assessment (yes = duration of the intervention was similar for all study groups).
YES, criterion was described and acceptable (1 point).
NO, criterion was not acceptable (0 points).
US, unsure, criterion was unclear or not described adequately (0 points).
TOT, total points of quality assessment (maximum of 12 points) (Furlan et al. 2009).

Electronic Supplementary Material Table S3: Characteristics of effective training interventions

Study	Intervention	Athletes	Adults	Adoles-cents	Males	Females	Pre-season	On season	Home-based	Warm-up	Stretching	Balance/ Coordination	Strenght/ power	Equipment	Progressive	Other
Askling et al. 2003	Eccentric strenght training programme	x	x		x		x						x	Resistance training		
Emery et al. 2005	Home-based balance training programme			x	x	x			x			x		Balance board		
Hupperets et al. 2009	Home based proprioceptive training programme	x	x	x	x	x			x			x		Balance board		
Mohammadi 2007	Proprioceptive training programme	x	x		x			x				x		Balance board	x	
Tropp et al. 1985	Ankle disk training	x	x		x		x	x				x		Balance board		
Verhagen et al. 2004	Balance board training programme	x	x		x	x		x		x		x		Balance board, ball	x	
Eils et al. 2010	Multistation proprioceptive exercise programme	x	x	x	x	x		x				x			x	
Emery & Meeuwisse 2010	Neuromuscular training program and home-based balance training programme	x		x	x	x			x	x	x	x	x	Balance board		
Emery et al. 2007	Basketball-spesific balance training programme	x		x	x	x		x	x	x		x		Balance board	x	
Pasanen et al. 2008	Neuromuscular training programme	x	x			x		x		X		x	x	Balance board, balance pad, medicine ball	x	
Wedderkopp et al. 1999	Ankle disk and functional warm-up training	x		x		x		x		x		x		Balance board		
Wedderkopp et al. 2003	Ankle disk and functional strenght training	x		x		x		x		x		x	x	Balance board		
Ekstrand et al. 1983	Prophylactic programme	x	x		x			x		x	x			Insoles, prophylactic taping		Controlled rehabilitation, correction and supervision
Heidt et al. 2000	Preseason training programme	x		x		x	x					x	x	Treadmill	x	
Holme et al. 1999	Rehabilitation programme	x	x		x	x						x	x	Balance board		Supervised physical therapy
Hägglund et al. 2007	Coach-controlled rehabilitation programme	x	x		x								x		x	10-step rehabilitation programme
LaBella et al. 2011	Neuromuscular warm-up programme	x		x		x		x		x		x	x			
Longo et al. 2012	Warm-up program me(The FIFA 11+)	x	x	x	x			x		x	x	x	x			
Olsen et al. 2005	Structured warm-up programme	x		x	x	x		x		x		x	x	Balance mat, balance board	x	
Soligard et al. 2008	Comprehensive warm-up programme (The 11+)	x		x		x		x		x		x	x			
Petersen et al. 2011	Eccentric training programme	x	x		x								x		x	

II

OVERUSE INJURIES IN YOUTH BASKETBALL AND FLOORBALL

by

Mari Leppänen, Kati Pasanen, Urho M. Kujala & Jari Parkkari 2015

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ORIGINAL RESEARCH

Overuse injuries in youth basketball and floorball

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Background: The popularity of team sports is growing among young people. High training volume and intensity may predispose young athletes to overuse injuries. Research to date has tended to focus on acute injuries rather than overuse injuries. The purpose of this study was to examine the occurrence, nature, and severity of overuse injuries in youth basketball and floorball, with the hypothesis that overuse injuries are frequent in youth team sports.

Methods: The study comprised a total of 401 Finnish team sports athletes (207 basketball and 194 floorball players). The data were collected using a detailed questionnaire. The participants (mean age 15.8±1.9 years) responded to the questionnaire covering information on overuse injuries during the previous 12 months.

Results: A total of 190 overuse injuries was reported (97 in basketball and 93 in floorball). In both sports, most of the injuries involved the lower extremities (66% and 55% of all injuries in basketball and floorball, respectively). In basketball, the most commonly injured site was the knee (44 cases, 45%). In floorball, the most commonly injured sites were the lower back/pelvis (36 cases, 39%) and knee (32 cases, 34%). Overuse injuries caused an average time loss from full participation of 26±50 (median 7) days in basketball and 16±37 (median 5) days in floorball.

Conclusion: Overuse injuries are a common problem in youth team sports, and often cause long-term absence from full participation. The findings suggest that injury reduction and training load monitoring strategies are needed in the field. More research using explicit prospective data collection is needed to better understand the problem.

Keywords: overuse injuries, sports injuries, epidemiology, adolescence, team sports

Introduction

Sports participation among the young is associated with multiple health benefits.[1,2] However, compared with less physically active adolescents, highly active adolescents seem to suffer more musculoskeletal pain,[3] such as a higher incidence of Osgood–Schlatter disease[4] and low back pain.[5] Overuse injuries in youth sports are of particular concern because they may cause long-term disability, negatively affect sports participation, and impact on performance and even daily activities.[6] Furthermore, repetitive physical overloading of the physis may in some cases result in growth disturbances and deformities.[7] Intensive training with a high training volume at an early age may predispose young athletes to overuse injuries.[8] Overuse injuries are common in endurance sports[9–11] and technical sports[12] that require long monotonous training sessions or repetitive movement patterns. However, overuse injuries may also be a substantial problem in team sports due to the high training volume and competition load.[13–15] Although interest in sports injury research has increased over the past decade,[16] there is little research on the incidence, prevalence, and prevention of overuse injuries.[12]

Basketball is a globally popular team sport.[17] Several earlier studies have investigated the epidemiology of basketball injuries in various populations, mainly among adult,[17] professional,[18–20] collegiate,[21,22] and high school[23,24] basketball players, but also more recently among children.[25–27] Regardless of the large number of studies published, analyses on the incidence and nature of overuse injuries in basketball are scarce. In addition, most of the studies published have been conducted outside Europe, and knowledge about basketball-related injuries in Europe is still insufficient.[17]

Floorball is a team sport that has become very popular in Europe, and is also one of the most popular team sports among the youth of Finland. In 2009–2010, there were 144,000 leisure-time floorball players among Finnish adolescents aged 3–18 years.[28] Floorball is a form of hockey played indoors on a court (20×40 m) surrounded by a low board. The players use sticks of graphite compounds to score goals with a hollow, dimpled plastic ball. A team usually consists of 15–20 players, and six players (a goalkeeper and five outfield players) are on the court at the same time. The playing time is three periods of 20 minutes. While the goalkeeper wears a helmet and padded clothes, the other players usually wear no protection or eye protection only. Although rough body contact is not allowed, floorball is associated with sudden accelerations, stops and turns, uncontrolled contacts with the boards, and strikes by sticks or the ball.[2] Thus far, only a few studies have investigated floorball injuries,[29–34] and these studies have focused mostly on adult players. Moreover, little information exists on overuse injuries in this sport.

Basketball and floorball are popular sports among young people in Finland. These sports are both played indoors and include similar movements, such as rapid turns, stops, and accelerations. Most epidemiological studies on basketball and floorball have focused on acute injuries. Thus, the purpose of this retrospective study of young basketball and floorball players was to examine the occurrence, nature, and severity of overuse injuries. The study hypothesis is that although most of the injuries in these sports are acute in nature, overuse injuries are common and often restrict normal training and playing for a long time.

Materials and methods

Participants

Study participants were recruited from basketball and floorball teams of the Tampere region. Altogether, 20 teams (with 475 junior players) were invited (ten basketball and ten floorball teams), and 18 teams (nine basketball and nine floorball teams) agreed to participate in the study. Of the participating teams, 37 players refused to take part in the study. Players were included if they were official members of the participating teams and had played official junior games (U16–U20) during the previous season. Players were excluded (n=3) if they had not participated in training and games during the previous season. A total of 401 players (207 basketball players and 194 floorball players) agreed to participate in the study. Participation in the study was based on written informed consent from each player, and the consent of a parent for subjects younger than 18 years was required. The study was approved by the ethics committee of the Pirkanmaa Hospital District, Tampere, Finland (ETL code R10169).

Data collection

This retrospective analysis is part of a large 3-year (2011–2014) follow-up study on sports injury risk factors. Injury occurrence in this report was analyzed retrospectively over a preceding 12-month period. The data used are based on a detailed questionnaire, which subjects completed when they entered the study (baseline). The questionnaire was based on a previous study of sports injuries,[32] and covered information on personal data, sports participation, and the history of sports injuries. The athletes were asked to evaluate as precisely as possible the number of weekly training sessions, the number of hours spent per session, and the number of games they played during the previous season. One part of the questionnaire concerned injury occurrence during participation in the player's sport. This part was completed if the athlete had sustained a sports injury in the preceding 12 months. For each injury that had occurred over the period of interest, the anatomic location, type of injury, the nature of injury (acute or overuse), context (contact or non-contact, training or competition), date of occurrence, and recovery time were registered. The collected data were systematically cross-checked with the athlete face-to-face to ensure the accuracy of the completed questionnaire.

Injury definitions and severity

An injury was defined as any physical complaint related to a game or practice that resulted in the player being unable to take full part in a game or practice session for at least one day. Any significant pain or discomfort that restricted normal training was taken into consideration. An overuse injury was defined as being caused by repetitive microtrauma without a single, identifiable event being responsible for injury.

The severity of the injuries was defined according to Fuller et al,[35] using time loss from full participation in the usual training program or competition: a minimal injury, an injury causing an absence from full participation of 1–3 days; a mild injury, an injury causing an absence from full participation of 4–7 days; a moderate injury, an injury causing an absence from full participation of 8–28 days; and a severe injury, an injury causing an absence from full participation of 29 or more days.

Exposure hours

Total hours of exposure were calculated as the sum of training and game hours per year. The total training hours per year for each player were calculated by the individually reported weekly training hours over the 45-week active period. Total exposure time during the games was calculated using an average of 60 minutes' active exposure time (including time spent in warm-up, playing, and cool-down) per game.

Injury rate and injury incidence

The injury rate was calculated as the number of injured players divided by the number of exposed players. Injury incidence per 1,000 hours of exposure was calculated by dividing the number of injuries by the total number of hours of exposure and then multiplying that figure by 1,000.

Statistical analysis

Means ± standard deviations were calculated to describe continuous variables, and frequencies and percentages were used for categorical variables. Differences in injury occurrence, injured body site, and injury severity between the boys and girls were analyzed using the chi-squared test. The independent samples *t*-test was used to compare group differences in characteristics of the participants. *P*-values <0.05 were considered to be statistically significant.

Results

Characteristics of the participants

A total of 401 junior players (213 boys and 188 girls) completed the questionnaire in the year they entered the study. The study population consisted of 207 basketball players (101 boys and 106 girls) and 194 floorball players (112 boys and 82 girls). The characteristics of the participants are shown in Table 1. The mean age of the participants at the time they entered the study was 15.8±1.9 (range 12–21) years. The boys were significantly older than the girls ($P=0.001$). The boys reported having started playing at a significantly ($P<0.001$) younger age than the girls (8.1±2.6 years versus 9.1±2.7 years, respectively). The average training volume per week was significantly ($P=0.001$) higher for the boys (10.2±3.9 hours per week) than the girls (9.0±3.0 hours per week).

Overall injury characteristics

In all, the 401 players included in the study reported a total of 629 injuries, comprising 439 acute injuries (70%) and 190 overuse injuries (30%). In basketball, the proportion of overuse injuries was 31% and in floorball the proportion was 30%. The incidence of overuse injury was 1.0 per 1,000 hours of exposure in both sports. The injured population consisted of 91 (60%) male players and 61 (40%) female players, of whom 80 (53%) were basketball players and 72 (47%) were floorball players. In addition, players reported a total of 150 overuse conditions that caused no time loss from training or competition; these were not included in the present analysis.

Table 1 Characteristics of the participants

	Basketball (n=207)		Floorball (n=194)		All (n=401)		*P*-value†
	Boys (n=101)	Girls (n=106)	Boys (n=112)	Girls (n=82)	Boys (n=213)	Girls (n=188)	
Age (years)	15.2±1.6	14.6±1.6	16.9±1.3	16.6±2.0	16.1±1.7	15.5±2.0	0.001**
Height (cm)	17.3±9.4	168.5±6.7	178.6±6.5	166.5±5.7	179.0±8.0	167.6±6.3	<0.001**
Weight (kg)	68.9±13.2	61.1±9.9	70.4±8.9	61.2±7.5	69.7±11.1	61.2±8.9	<0.001**
BMI (kg/m^2)	21.3±3.1	21.5±2.9	22.0±2.4	22.1±2.6	21.7±2.7	21.7±2.8	0.848
Age when started to play (years)	7.9±2.3	8.1±2.3	8.2±2.9	10.4±2.6	8.1±2.6	9.1±2.7	<0.001**
Ever played in adult elite league level							
Yes (%)	4.0	1.9	7.1	30.5	5.6	14.4	
No (%)	96.0	98.1	92.9	69.3	94.4	85.6	
Training sessions/week	4.5±1.4	4.1±1.2	4.1±1.5	3.5±1.0	4.3±1.5	3.8±1.2	<0.001**
Training hours/week	9.8±3.2	8.9±3.0	10.6±4.4	9.1±3.1	10.2±3.9	9.0±3.0	<0.001**
Games/season	32.7±14.8	38.1±17.5	37.4±15.4	35.7±15.0	35.2±15.3	37.1±16.5	0.237

Notes: Values are presented as mean ± standard deviation; †*P*-values for sex differences among all participants; ***P*-value <0.05 considered to be statistically significant.
Abbreviation: BMI, body mass index.

Basketball

Of the 207 basketball players participating in the study, 80 (39%) had sustained at least one overuse injury in the preceding 12 months. The boys had sustained 44 (45%) overuse injuries and the girls 53 (55%), giving a total of 97 overuse injuries among the basketball players. The injury rate was 0.47 overuse injuries per athlete per year.

Most of the overuse injuries in basketball involved the lower extremities (64 cases, 66%), with the knee being the most commonly injured site (44 cases, 45%, Table 2). Overuse injuries caused an average time loss from full participation of 26±50 (median 7) days. The severity of injuries is presented in Table 3. In basketball, there were no differences for the anatomic location (Figure 1) or severity of overuse injuries between the boys and the girls.

Floorball

Of the 194 floorball players, 72 (37%) reported having had at least one overuse injury in the preceding 12 months. Significantly more boys (51 players) reported overuse injury/injuries than girls (21 players, P=0.005). Floorball players sustained a total of 93 overuse injuries, of which the boys sustained 65 (70%) overuse injuries and the girls 28 (30%) overuse injuries. The injury rate in floorball was 0.48 overuse injuries per athlete per year.

Most of the overuse injuries involved the lower extremities (51 cases, 55%). The most commonly injured site was the lower back/pelvis (36 cases, 39%), and the second most common site was the knee (32 cases, 34%, Table 2). There were differences in anatomic location of overuse injuries between the boys and girls; the boys reported significantly more lower back and knee overuse injuries compared with the girls ($P<0.001$, Figure 2). Most of the injuries were classified as minimal (Table 3). There was no difference in severity of overuse injuries between the boys and girls (P=0.544). The average time loss from full participation due to an overuse injury was 16±37 (median 5) days.

Discussion

The main finding of this retrospective study was that 39% of basketball players and 37% of floorball players reported having had at least one overuse injury during the preceding 12-month period. Overuse injuries caused long absences from full participation in training and playing in both sports. Most of the overuse injuries in these sports affected the lower extremities, with the knee and lower back/pelvis being the most commonly injured sites.

Epidemiological studies of overuse injuries in team sports are scarce, especially among young people. Previous studies in older populations of floorball players have reported that approximately 17%–24% of all floorball injuries are overuse injuries.[30,31] In a study of female players only,[33] the percentage of overuse injuries was 30%. In our study, the proportion of overuse injuries among young floorball players was similar (30%). According to previous studies among professional basketball players,[18,19,36] overuse injuries and inflammatory conditions account for 15%–27% of all injuries. In our study, 31% of all basketball injuries were overuse injuries. However, Clarsen et al[37] recently found that overuse injuries tend to be underreported, so the actual proportion of overuse

Table 2 Frequency (n) and anatomical distribution of overuse injuries according to game and sex, with distribution of overuse injuries according to injury severity

	Basketball (n=97)			Floorball (n=93)		
	Boys (n=44)	Girls (n=53)	Total	Boys (n=65)	Girls (n=28)	Total
All	44 (16/6/6/16)	53 (21/11/10/11)	97 (37/17/16/27)	65 (30/12/16/7)	28 (11/4/11/2)	93 (41/16/27/9)
Head/neck	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)
Upper body	0 (0/0/0/0)	1 (1/0/0/0)	1 (1/0/0/0)	0 (0/0/0/0)	2 (1/1/0/0)	2 (1/1/0/0)
Trunk	15 (10/2/1/2)	17 (11/2/2/2)	32 (21/4/3/4)	32 (17/4/7/4)	8 (6/0/2/0)	40 (23/4/9/4)
Upper back/chest	0 (0/0/0/0)	1 (1/0/0/0)	1 (1/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)	0 (0/0/0/0)
Lower back/pelvis	11 (7/2/1/1)	16 (10/2/2/2)	27 (17/4/3/3)	29 (16/4/6/3)	7 (5/0/2/0)	36 (21/4/8/3)
Hip/groin	4 (3/0/0/1)	0 (0/0/0/0)	4 (3/0/0/1)	3 (1/0/1/1)	1 (1/0/0/0)	4 (2/0/1/1)
Lower extremities	29 (6/4/5/14)	35 (9/9/8/9)	64 (15/13/13/23)	33 (13/8/9/3)	18 (4/3/9/2)	51 (17/11/18/5)
Thigh	0 (0/0/0/0)	1 (0/1/0/0)	1 (0/1/0/0)	6 (4/1/1/0)	0 (0/0/0/0)	6 (4/1/1/0)
Knee	22 (5/2/4/11)	22 (7/4/6/5)	44 (12/6/10/16)	25 (8/7/7/3)	7 (2/2/2/1)	32 (10/9/9/4)
Shin/calf	4 (1/1/0/2)	7 (1/2/2/2)	11 (2/3/2/4)	1 (1/0/0/0)	6 (0/0/5/1)	7 (1/0/5/1)
Ankle	1 (0/1/0/0)	4 (1/1/0/2)	5 (1/2/0/2)	1 (0/0/1/0)	2 (1/0/1/0)	3 (1/0/2/0)
Foot	2 (0/0/1/1)	1 (0/1/0/0)	3 (0/1/1/1)	0 (0/0/0/0)	3 (1/1/1/0)	3 (1/1/1/0)

Note: n, number of injuries (minimal/mild/moderate/severe).

Table 3 Severity of overuse injuries (n=190) according to sports and sex

Injury severity	Basketball			Floorball		
	Boys	**Girls**	**Total**	**Boys**	**Girls**	**Total**
Minimal, 1–3 days	16 (36)	21 (40)	37 (38)	30 (46)	11 (39)	41 (44)
Mild, 4–7 days	6 (14)	11 (21)	17 (18)	12 (19)	4 (14)	16 (17)
Moderate, 8–28 days	6 (14)	10 (19)	16 (17)	16 (25)	11 (39)	27 (29)
Severe, ≥29 days	16 (36)	11 (21)	27 (28)	7 (11)	2 (7)	9 (10)
Total	44 (100)	53 (100)	97 (100)	65 (100)	28 (100)	93 (100)

Note: Values are presented as number of injuries (% rounded).

injuries is probably much higher than these rates suggest. Our results, which show that the most common injury location causing long-term losses in playing time was the knee, are in accordance with previous findings that growing athletes commonly suffer from Osgood–Schlatter disease,[4] patellofemoral pain, or other long-lasting but self-limiting unspecified knee pain.[38]

When describing the occurrence of overuse injuries, the definition used to record these injuries is important. We used the definition "time lost from full participation in the usual training program or competition" and found an overuse injury incidence of 1.0 injuries per 1,000 hours of exposure in both sports. Unfortunately, we were not able to find a reference incidence for either youth sport. In their prospective cohort study of senior basketball players, Cumps et al[17] used an injury definition based on physical discomfort rather than time loss, and found an overuse injury incidence of 3.8 per 1,000 hours of exposure, which is considerably higher than the incidence in youth basketball in our study. Although these rates are not comparable due to different study designs and methods, it can be speculated that the injury definition we used may have underestimated the true extent of overuse injuries. Standard injury surveillance methods (time loss) are not able to register all overuse injuries because overuse problems often have a gradual onset and athletes tend to train and compete despite their symptoms.[37] It is worth noting that players in our study reported 150 overuse conditions that caused no time loss and hence were not defined as injuries, but it is most likely that these injuries were still harmful. Including these conditions in the present analysis would give an overuse injury incidence of 1.8 per 1,000 hours of exposure.

The present finding that most of the overuse injuries in both basketball and floorball are located in the lower extremities, with the knee being the most common site of an overuse injury, is consistent with previous research.[17,30,31,33] There is evidence in the literature that overuse knee conditions, such as patellofemoral pain, are common, especially in elite-level basketball.[17,19,20,36] In team sports that require jumping (volleyball, basketball), the high training load is commonly reported as a risk factor for patellar tendinopathy.[15,17,39] Furthermore, recent findings indicate that smaller tendon cross-sectional area might also be related to patellar tendinopathy.[40] While adolescent athletes rapidly increase their muscle strength, tendon stiffness and cross-sectional area are not similarly developed, and this may predispose adolescent athletes to tendon overuse injuries.[41] Pains in the tendon insertions and associated tendon-related problems are common in youth team sports that involve repetitious impact movements such as landing

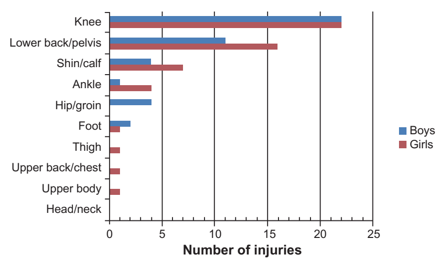

Figure 1 Overuse injuries in basketball according to anatomic location and sex.

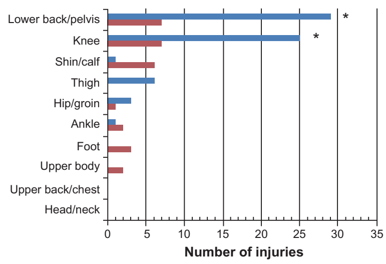

Figure 2 Overuse injuries in floorball according to anatomic location and sex.
Note: *Significant difference at $P<0.001$.

from a jump and sudden stops.[4] Surprisingly, according to our results, overuse conditions of the lower back were almost as common as knee problems in basketball, and in floorball they were even more common. In floorball, a plausible explanation for this might be the low playing position, which causes strain to the lower back.

It is well known that injury profiles vary by sport,[10] but there is insufficient evidence regarding whether male and female team sport athletes have different risks for overuse conditions. Many authors have found that patellar tendinopathy is far more common in male athletes than in female athletes.[13,15,42] However, this is not the case in all sports and overuse conditions. Cumps et al[17] reported that female basketball players are at a higher risk for all overuse injuries and for patellofemoral pain. Snellman et al[32] reported overuse injuries in floorball being more common in females, whereas Wikström and Andersson[31] found the opposite. In the current study, there were no sex differences in basketball, but in floorball the boys seemed to have sustained overuse injuries more often than the girls. Sex differences might partly be explained by differences in training volumes.[43] More studies are therefore needed to determine the possible role of sex as a risk factor for overuse injuries in team sports as well as in other sports.

This study has some limitations. First, there is recall bias affecting the reliability of the retrospectively collected injury history. In addition, we were not able to confirm detailed diagnoses. Second, we calculated exposure hours based on individually reported data and by using average values for training and playing. Thus, it is possible that some players played less and some more than our estimation. Further, the injury definition based on time loss, although emphasizing time loss from full participation in training or competition, might have left aside injuries that caused no time loss or were transient in nature. It is possible that this might have resulted in underestimation of the frequency and severity of overuse injuries. These results should therefore be interpreted with caution. In addition, in our study, the age of the participants ranged from 12 to 21 years, and these findings cannot be extrapolated to immature adolescent athletes or to adult athletes.

The strengths of this study are the accuracy of the completed questionnaire and the high response rate. We collected the data on the day the player entered the study, and completed the questionnaire on the spot, meaning that a study researcher was able to carefully check the completed questionnaire with the player. All participating players completed the questionnaire.

Conclusion

Overuse injuries among growing athletes in youth team sports have not been well studied. The present findings provide evidence that overuse injuries are quite a common problem among youth basketball and floorball players, and overuse injuries often have a long-term injurious effect on the player's ability to practice and compete at full capacity. Notwithstanding the limitations of retrospectively collected data, our findings suggest that development of injury reduction and training load monitoring strategies is needed in the field. Prospective analyses of risk factors for overuse injuries in popular youth team sports are also needed. In order to understand the true extent of the problem, future studies should use standardized methods to register overuse problems.

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Disclosure

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III

KNEE CONTROL AND JUMP-LANDING TECHNIQUE IN YOUNG BASKETBALL AND FLOORBALL PLAYERS

by

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Knee control and jump-landing technique in young basketball and floorball players

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Abstract

Poor knee alignment is associated with increased loading of the joints, ligaments and tendons, and may increase the risk of injury. The study purpose was to compare differences in knee kinematics between basketball and floorball players during a vertical drop jump (VDJ) task. We wanted to investigate whether basketball players, whose sport includes frequent jump-landings, exhibited better knee control compared with floorball players, whose sport involves less jumping.

Complete data was obtained from 173 basketball and 141 floorball players. Peak knee valgus and flexion angles during the VDJ were analyzed by 3D motion analysis.

Larger knee valgus angles were observed among basketball players (-3.2º, 95%CI -4.5 to -2.0) compared with floorball players (-0.9º, 95%CI -2.3 to 0.6) (*P*=0.022). Basketball players landed with a decreased peak knee flexion angle (83.1º, 95%CI 81.4 to 84.8) compared with floorball players (86.5º, 95%CI 84.6 to 88.4) (*P*=0.016). There were no significant differences in height, weight or BMI between basketball and floorball players. Female athletes exhibited significantly greater valgus angles than males.

This study revealed that proper knee control during jump-landing does not seem to develop in young athletes simply by playing the sport, despite the fact that jump-landings occur frequently in practice and games.

Key words: knee alignment, knee kinematics, injury risk, adolescents, team sports

Introduction

Good knee control is essential in team sports that require pivoting and jumping. Unfavourable knee joint alignment (specifically increased knee valgus and decreased knee flexion movements) during sporting tasks is associated with increased loading of the joints, ligaments and tendons, and may contribute to acute and overuse knee injuries, such as patellofemoral pain (PFP) and anterior cruciate ligament (ACL) injury [3, 9, 12, 15, 21, 27].

In order to identify athletes with poor knee control, different screening methods have been studied. The vertical drop jump (VDJ) test is widely used for assessing lower extremity alignment [2, 5, 9, 23, 26]. Knee joint kinematics during drop-jump landing can be measured reliably by using three-dimensional (3D) motion analysis [6]. The test can also be executed without any measurement equipment, by using real-time subjective assessment of frontal-plane knee control [24, 31], and can therefore be easily implemented for screening of athletes at all ages and levels.

Excessive knee valgus angle during a jump-landing task seems to be more common among female than male athletes [5, 11]. Females also have a higher incidence of ACL injury [1, 20] and PFP [22, 32]. Knee valgus angle during a drop jump task has a strong correlation with valgus moment, which has also been identified as a risk factor for ACL injury [9]. Previous studies have investigated knee biomechanics during VDJ landing in some team sports, such as basketball, volleyball, and soccer [9, 23]. Floorball is another popular team sport in Europe, and has a high incidence of knee injuries [28].

The purpose of the study is to investigate whether basketball players, whose sport requires frequent jump-landings, exhibit better knee control during jump-landing compared with floorball players, whose sport involves less jumping. Furthermore, this study examines how common excessive knee joint valgus movement is among this young population and whether there are gender differences in knee control. We hypothesized that basketball players would demonstrate better landing technique in VDJ test compared with floorball players, because they are more used to perform jumping. This study offers some important insights into the role of frequent jump-landings on frontal plane knee control. The results further help understanding the magnitude of the knee control problem in youth team sports and implementing training programs to prevent knee injuries.

Materials and methods

Participants

Players were recruited from six basketball and floorball clubs of the Tampere City district, Finland. We invited altogether 475 players from the two highest junior league levels to participate in a baseline screening tests as a part of a prospective cohort study investigating risk factors for sports injuries. Players who were junior-aged (U21) and official members of the participating teams were eligible for participation. Of the invited players, 71 players declined to take part in the study. During the three study years, a total of 404 players (209 basketball players and 195 floorball players) volunteered to participate in the study. One hundred and eighteen players entered the study in May 2011, 84 players in May 2012 and 202 players in May 2013.

Players signed a written informed consent form before inclusion (including parental consent for players aged <18 years). The study was conducted in accordance with the Declaration of Helsinki, and was approved by Ethical Committee of the Pirkanmaa Hospital District, Tampere, Finland (ETL-code R10169). The study follows the ethical standards of the International Journal of Sports Medicine [8].

Of the 404 players in the study, 57 players did not participate in the VDJ test due to ongoing injury or illness. In addition, the test results of 33 players were excluded from the analysis due to gaps in marker trajectories that could not be interpolated. In most of these cases, the ASIS (anterior superior iliac spine) markers were occluded by the player's upper body in the bottom phase of the jump due to a deep landing strategy. Complete data was obtained from 314 players (173 basketball and 141 floorball players), of which 161 were female and 153 male. The characteristics of the participants are shown in Table 1. The mean (SD) age of the participants at the time of entering the study was 15.7 ± 1.8 years (range 12–21 years). The basketball players were younger than the floorball players (mean age 14.8 ± 1.6 years and 16.7 ± 1.4 years for basketball and floorball, respectively) ($p<.001$). There were no significant differences in height, weight or BMI between basketball and floorball players.

Test protocol

Each participant underwent a series of screening tests performed in 3D motion analysis laboratory at the year they enrolled the study. One part of this test battery was a vertical drop jump task from a 30 cm box (Fig. 1). The testing protocol was adopted from the risk factor study by Nilstad et al. [23].

The players wore a tight shorts and indoor sports shoes during the test. Male players were shirtless, whereas female players used sports bras. We measured height and weight, as well as knee and ankle joint widths. Sixteen reflective markers were placed over anatomical landmarks on the lower extremities according to the Plug-In Gait marker set (Vicon Nexus v1.7; Oxford Metrics, Oxford, UK) (on the shoe over the second metatarsal head and over the posterior calcaneus, lateral malleolus, lateral shank, lateral knee, lateral thigh, anterior superior iliac spine, posterior superior iliac spine). Prior to the drop jump task, the subjects had performed a standardized warm-up procedure.

We instructed players to drop off a 30 cm box and perform a maximal jump upon landing with their feet on two separate force platforms (AMTI BP6001200; AMTI, Watertown, MA). Participants were allowed to practice the task up to three times. A minimum of three successful trials were collected from each participant. A trial was considered valid if the participant landed with one foot on each of the adjacent force platforms and performed a maximal vertical jump after the first landing.

Eight high-speed cameras (Vicon T40, Vicon) and two force platforms were used to record marker positions and ground reaction force data synchronously at 300 and 1500 Hz, respectively. A static calibration trial was completed prior to task to determine the anatomical segment coordinate systems. Marker trajectories were identified with the Vicon Nexus software (Vicon Nexus v1.7; Oxford Metrics). Interpolation using the Pattern Fill algorithm was performed if the markers disappeared momentarily (time period of 25 frames or less). We excluded trials if the reflective markers were out of sight for longer than 25 frames. Both movement and ground reaction force were filtered using a fourth-order Butterworth filter with cutoff frequencies of 15 Hz [14].

Data analyses were performed using the Plug-in Gait model (Vicon Nexus v1.7, Oxford Metrics). Knee angles were determined across three successful trials. Peak knee valgus angles and peak knee flexion angles during the landing phase of the drop jump task were recorded. Both legs were analyzed and the mean angle for each trial was calculated and used in the analyses. The landing phase was defined as the period when the ground reaction force exceeded 20 N. Based on the average values of three trials for each subject, frontal plane knee control was classified as good (varus angles >0.0º), reduced (valgus angles ranging between -0º to -10º) or poor (valgus angles <-10.0º) (modified according to Fox et al. [7] and Nilstad et al.[24].

Statistical analysis

Independent samples t-test was used for statistical comparisons of the participants. A multivariate analysis of variance with age as a covariant was used to determine the effect of gender (male vs. female) and sport (basketball vs. floorball) on peak knee valgus angle and peak knee flexion angle. Chi-square test was used to compare gender differences in frontal plane knee control (categorical variable). P-values less than 0.05 were considered significant.

Results

Significantly larger peak knee valgus angles were observed in the basketball players compared with the floorball players (*P*=0.022). The age adjusted mean peak valgus angle was -3.2º (95% CI, -4.5 to -2.0) in basketball and -0.9º (95% CI, -2.3 to 0.6) in floorball. The female athletes exhibited significantly (*P*<0.001) larger peak knee valgus angles (-7.5º, 95% CI, -8.7 to -6.2) than the male athletes (3.4º, 95% CI, 2.1 to 4.6) (Table 2).

The basketball players landed with a decreased peak knee flexion angle (83.1º, 95% CI, 81.4 to 84.8) compared with the floorball players (86.5º, 95% CI, 84.6 to 88.4) (*P*=0.016) (Table 2). There were no differences in the peak knee flexion angles between the male (84.5º, 95% CI, 82.8 to 86.2) and female players (85.1º, 95% CI, 83.5 to 86.8).

When mean values of the peak knee valgus/varus angles (range -52.9º to 14.6º) were classified into three categories, fifty-one percent of all players landed with a good frontal plane knee control. Reduced knee control was observed among 28% and poor knee control among the remaining 21% of the players (Table 3). The results differed considerably according to gender: only 22% of the female players were classified as having a good knee control compared with 80% of the male players (*P*<0.001).

Discussion

Basketball players exhibited larger peak knee valgus angles during the jump-landing compared with floorball players. The basketball players also landed with a decreased peak knee flexion angle compared with the floorball players. Half of the young team sport players had difficulties maintaining a good knee joint control during the VDJ task. The higher proportion of female players with poor knee control is in line with earlier studies [4, 5, 11, 18].

The vertical drop jump task simulates rebounding in basketball [2] and it is designed to screen athlete's ability to maintain good knee alignment in an impact. Serious injuries typically occur during rapid movements, such as landing from a jump or changing direction [12, 15, 27]. Floorball is a ballgame which includes accelerations, running, stopping and changing directions, but involves less jumping and rebound movements. Contrary to our expectations that basketball players would benefit from jump and rebound practice, the results revealed that the basketball players actually landed with a greater peak knee valgus compared with the floorball players. Furthermore, the basketball players tended to have more extended knees during the landing phase compared with the floorball players. These findings indicate that good knee control is not developed simply by playing the sport. Hence, more focused training is needed to improving the ability to control the knee alignment during jump-landing [10, 30]. Studies have shown that lower limb alignment can be changed by specific neuromuscular training program [25, 26]. Neuromuscular training is also effective to increase pre-activation of the hamstring muscles during sidecutting [33] and to prevent injuries [17, 29]. Thus, more attention should be paid to enhance the knee control of young athletes and also to teach them safe movement techniques.

The current study has a high sample size and utilizes 3D motion analysis, which has been referred to as the gold standard for assessing lower extremity kinematics and kinetics [19, 24]. Nevertheless, marker-based motion analysis has limitations. The kinematical calculations are highly dependent upon marker placement and may also be influenced by soft-tissue movement artifact [16]. However, because we had large groups and all subjects-groups were equally exposed to these methodological issues, it is unlikely that the consistent group differences in this study were due to measurement errors. Another limitation is that we were not able to include the data from 33 players (9 basketball players and 24 floorball players) due to gaps in marker trajectories. Furthermore, the valgus angles between legs were averaged, which might underestimate the results if there were high asymmetry between sides.

The current investigation focused on knee valgus and flexion angles to study knee control. By adding more variables, such as external/internal rotation or valgus moment, we would have been able to provide a better understanding of knee loading. However, previous studies have revealed a high correlation between valgus angle and valgus moment during a jump-landing task [9]. Valgus angle in jump-landing also correlates moderately with valgus in sidestep cutting maneuver [13], another sports movement known to cause knee injuries [15]. Moreover, the VDJ test can be used as a field test to examine knee valgus and knee flexion angles without any measurement equipment [24]. The test is simple, easy to use and learn, also for nonprofessional coaches and team staff. The basketball players were approximately two years younger than the floorball players. Thus, their physical strength and skills might be less developed. We used age-adjustment in our analyses, and since there were no other group differences in anthropometrics (height, weight or BMI), we believe the groups were comparable.

Conclusions and implications

This study investigating dynamic knee control and jump-landing technique among young team sport athletes revealed that basketball players who are used to performing jumps and rebounds, in fact demonstrated poorer knee control during jump-landing compared with floorball players, whose sport involves less jumping. Poor knee control was especially common among young female athletes. An important clinical implication of these findings is that young team sport athletes need to be taught a safer technique for landing and also need specific neuromuscular training in order to avoid potentially harmful movement patterns. A natural progression of this work is to analyze biomechanical risk factors for acute and overuse knee injuries among young team sport population.

Competing interest

The authors declare that there are no conflicts of interests regarding the publication of this paper.

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Table 1. Characteristics of the participants (n=314). *Mean ± SD; **P-value <0.05 regarded as significant.

	Basketball (n=173)		Floorball (n=141)		All (n=314)			All (n=314)		
	Male (n=79)	Female (n=94)	Male (n=74)	Female (n=67)	Male (n=153)	Female (n=161)	p-value	Basketball (n=173)	Floorball (n=141)	p-value
Age (years)*	15.2 ± 1.6	14.6 ± 1.6	16.7 ± 1.2	16.6 ± 1.7	15.9 ± 1.5	15.4 ± 1.9	0.007**	14.8 ± 1.6	16.7 ± 1.4	<0.001 **
Height (cm)*	179.4 ± 9.1	168.4 ± 6.7	178.6 ± 6.7	166.6 ± 5.8	179.0 ± 8.0	167.7 ± 6.4	<0.001**	173.4 ± 9.6	172.9 ± 8.7	0.622
Weight (kg)*	68.2 ± 12.9	60.8 ± 9.7	68.9 ± 8.1	60.9 ± 6.5	68.5 ± 10.8	60.8 ± 8.5	<0.001**	64.2 ± 11.8	65.1 ± 8.4	0.416
BMI*	21.1 ± 3.0	21.4 ± 2.7	21.6 ± 2.2	21.9 ± 2.0	21.3 ± 2.7	21.6 ± 2.5	0.329	21.2 ± 2.9	21.7 ± 2.1	0.067

Table 2. Peak knee varus/valgus and flexion angles (age adjusted) according to gender and sport. Mean (95% CI); *Negative values referring to valgus and positive to varus movement; **P-value <0.05 regarded as significant.

	Male (n=153)	Female (n=161)	p-value	Basketball (n=173)	Floorball (n=141)	p-value
Peak knee varus/valgus* angle; mean (95% CI)	3.4 (2.1–4.6)	-7.5 (-8.7– -6.2)	<0.001**	-3.2 (-4.5– -2.0)	-0.9 (-2.3–0.6)	0.022**
Peak knee flexion angle; mean (95% CI)	84.5 (82.8–86.2)	85.1 (83.5–86.8)	0.607	83.1 (81.4–84.8)	86.5 (84.6–88.4)	0.016**

Table 3. Frontal plane knee control according to sport and gender. n (%). Knee control classified into three categories according to peak knee valgus/varus angle: good (varus angles >0.0º), reduced (valgus angles ranging between -0º to -10º) and poor knee control (valgus angles <-10.0º).

	Basketball (n=173)			Floorball (n=141)			
	Male	Female	All	Male	Female	All	Total
Good knee control	59 (75%)	20 (21%)	79 (46%)	64 (87%)	16 (24%)	80 (57%)	159 (51%)
Reduced knee control	16 (20%)	40 (43%)	56 (342%)	8 (11%)	25 (37%)	33 (23%)	89 (28%)
Poor knee control	4 (5%)	34 (36%)	38 (22%)	2 (3%)	26 (39%)	28 (20%)	66 (21%)
Total	79 (100%)	94 (100%)	173 (100%)	74 (100%)	67 (100%)	141 (100%)	314 (100%)

Figure 1. Vertical drop jump -test in 3-D motion laboratory.

IV

STIFF LANDINGS ARE ASSOCIATED WITH INCREASED ACL INJURY RISK IN YOUNG FEMALE BASKETBALL AND FLOORBALL PLAYERS

by

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