



KATI PASANEN

Floorball Injuries

Epidemiology and injury prevention
by neuromuscular training



ACADEMIC DISSERTATION

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, which are referred to in the text by the Roman numerals I-V:

- I Parkkari J, Pasanen K, Mattila V, Kannus P, Rimpelä A (2008): The risk for a cruciate ligament injury of the knee in adolescents and young adults: a population-based cohort study of 46 500 people with a 9 year follow-up. *Br J Sports Med* 42:422-426.
- II Pasanen K, Parkkari J, Kannus P, Rossi L, Palvanen M, Natri A, Järvinen M (2008): Injury risk in female floorball: a prospective one-season follow-up. *Scand J Med Sci Sports* 18:49-54.
- III Pasanen K, Parkkari J, Rossi L, Kannus P (2008): Artificial playing surface increases the injury risk in pivoting indoor sports: a prospective one-season follow-up in Finnish female floorball. *Br J Sports Med* 42:194-197.
- IV Pasanen K, Parkkari J, Pasanen M, Hiilloskorpi H, Mäkinen T, Järvinen M, Kannus P (2008): Neuromuscular training and the risk of leg injuries in female floorball players: cluster randomised controlled study. *BMJ* 337:96-102.
- V Pasanen K, Parkkari J, Pasanen M, Kannus P (2009): Effect of a neuromuscular warm-up programme on muscle power, balance, speed and agility – A randomised controlled study. *Br J Sports Med* (in press). Published Online First: doi:10.1136/bjsm.2009.061747

ABBREVIATIONS

ACL	anterior cruciate ligament
AHLS	Adolescent Health and Lifestyle Survey
AIS	abbreviated injury scale
ANOVA	analysis of variance
ATFL	anterior talofibular ligament
BMI	body mass index
CDS	Cause-of-Death Statistics
CFL	calcaneofibular ligament
CI	confidence interval
FPRC	Finnish Population Register Center
HR	hazard ratio
ICC	intra-cluster correlation coefficient
ICD	International Classification of Diseases
IRR	incidence rate ratio
ITT	intention-to-treat
OR	odds ratio
NHDR	National Hospital Discharge Register
PCL	posterior cruciate ligament
PTFL	posterior talofibular ligament
Q angle	quadriceps femoris angle
RCT	randomized controlled trial
1 RM	one repetition maximum
RR	rate ratio
SD	standard deviation

ABSTRACT

Floorball has become a popular sport in Finland during the past decade. The game is associated with sudden accelerations, decelerations, and twisting turns, and thus it is not surprising that lower limb injuries are common in floorball. Studies from other sports have reported that neuromuscular training can reduce injury risk in athletes. However, no previous study has assessed possibilities for preventing floorball injuries.

The purpose of this dissertation was to investigate epidemiology of sports injuries in female athletes, and examine whether a neuromuscular warm-up program, designed to enhance body control and motor skills, was effective in preventing non-contact lower extremity injuries in female floorball players.

First, the occurrence of cruciate ligament injuries of the knee among Finnish adolescents and young adults was examined. The total cohort of 46 472 was followed for an average of nine years. The analysis was based on longitudinal data of the Adolescent Health and Lifestyle Surveys linked to the National Hospital Discharge Register and Cause-of-Death Statistics.

The results indicated that young people who participate in structured sports had a clearly higher risk for cruciate ligament injury than their less active counterparts. In highest activity level, that is participation ≥ 4 times a week in organized sports, the injury risk increased substantially in females (HR=8.5; 95% CI 4.3 to 16.4) than males (HR=4.0; 95% CI 2.7 to 6.1).

The following two studies investigated the epidemiology of floorball injuries in female players. In the first of them, 374 licensed players from the three Finnish top leagues were observed prospectively for one competitive season (6-month). The outcome variable was a floorball-related time-loss injury. The practice and game hours were recorded on an exercise diary and all injuries were registered with a structured questionnaire and verified by a physician.

During the floorball season, a total of 172 time-loss injuries occurred in these 374 female players. Injury rate was strikingly higher in floorball games (40.3 injuries / 1000 game hours) than in practice (1.8 / 1000 training hours). Most commonly injured body sites were the knee (27%), ankle (22%), and thigh (12%). 121 of the injuries were acute and 51 were from overuse. Most of the acute injuries involved

the ankle and knee (29% and 28%), and about half of acute ankle and knee injuries (59% and 46%) occurred in non-contact circumstances.

The second epidemiological study on floorball injuries examined the interaction between playing surface and injury risk. The data was based on the previous study including players from two top level leagues (n=331). The outcome variable was an acute game-related time-loss injury. Information on the floor type (parquet or artificial floor) at each game was given by the Finnish Floorball Association. This study suggested that the risk for acute injury was two-fold higher on artificial than wooden floors (IRR=2.1; 95% CI 1.2 to 3.5). Moreover, the risk for non-contact and severe injury was clearly increased on artificial surfaces.

Thereafter, an intervention study was constructed according to the findings from the previous three studies. This randomized controlled trial assessed the effects of neuromuscular warm-up program on injury risk of female floorball players. The main outcome variable was an acute non-contact injury of lower extremity.

28 Finnish female floorball teams (n=457) participated, and stratified cluster randomization to the intervention and control group was performed at each league level (elite league, 1st division, and 2nd division). Teams in the intervention group attended in a structured warm-up program that consisted of running technique, balance, jumping, and strength exercises. Results showed that the neuromuscular warm-up program reduced the injury risk considerably: 66% fewer non-contact lower extremity injuries (IRR=0.34; 95% CI 0.20 to 0.57) occurred in the intervention group compared with the control group.

Related to the above noted intervention, the final study described the effects of the warm-up program on muscle power, balance, speed and agility of the players. Outcomes were the follow-up test results from five field tests: static jump, countermovement jump, jumping over a bar, standing on a bar, and figure-of-eight running. All players who participated in baseline and follow-up tests (n=222) were included in the analyses. Results from this study attested that, in contrast to control group, the intervention group improved significantly static balance and sideways jumping speed.

Altogether, the findings of this dissertation indicate that injuries to lower extremities, especially those involving ankle and knee joint in non-contact circumstances, are common among female floorball players. However, a neuromuscular warm-up program designed to enhance motor skills and body control

can clearly reduce the injury risk. Additionally, the warm-up program improves the players' static balance and sideways jumping speed. Hence, neuromuscular warm-up exercises can be recommended to be included in the weekly training of female athletes who participate in pivoting and cutting sports.

TIIVISTELMÄ

Viimeisen kymmenen vuoden aikana salibandyn harrastaminen on lisääntynyt voimakkaasti Suomessa. Salibandy sisältää nopeita liikkeelle lähtöjä, äkillisiä jarrutuksia ja suunnanmuutoksia, joten ei ole yllättävää, että lajissa sattuu runsaasti nilkka- ja polvivammoja. Muissa lajeissa tehdyt tutkimukset ovat osoittaneet, että hermolihaskäytön toimintaa kehittäväillä harjoituksilla voidaan vähentää urheilijoiden vammatariskia. Salibandyssä vammojen ehkäisymahdollisuutta ei ole aikaisemmin tutkittu.

Tämän väitöskirjan tavoitteena oli tutkia naisurheilijoiden urheiluvammojen epidemiologiaa ja selvittää olisiko hermolihaskäytön aktivoivan alkuverryttelyohjelman avulla mahdollista vähentää ilman kontaktia tapahtuvien alaraajavammojen riskiä naisten salibandyssä.

Ensimmäisessä osatyössä selvitettiin polven ristisidevammojen yleisyyttä suomalaisten nuorten keskuudessa. Tutkimuksessa seurattiin 46 472 nuorta keskimäärin yhdeksän vuoden ajan. Tutkimus perustui Nuorten Terveystapatutkimuksen aineistoon, joka yhdistettiin valtakunnalliseen hoitoilmoitus- ja kuolinsyyrekisteriin.

Tutkimus osoitti, että ristisidevamman riski on selvästi korkeampi niillä nuorilla, jotka osallistuvat aktiiviseen liikuntaan urheiluseurassa. Korkeimmalla fyysisen aktiivisuuden tasolla (osallistuminen ≥ 4 kertaa viikossa aktiiviseen liikuntaan urheiluseurassa) naisten vammatariski (HR=8.5; 95% LV 4.3-16.4) kasvoi huomattavasti enemmän kuin miesten (HR=4.0; 95% LV 2.7-6.1).

Seuraavissa kahdessa osatyössä tutkittiin salibandyvammojen epidemiologiaa. Yhden pelikauden mittaiseen (6 kk) seurantatutkimukseen osallistui 374 salibandyn kilpapelaja kolmelta ylimmältä sarjatasolta. Päävastemuuttujana tässä tutkimuksessa oli salibandyn yhteydessä sattunut vamma, joka aiheutti vähintään vuorokauden poissaolon urheiluharjoittelusta. Harjoitus- ja pelitunnit kerättiin

harjoituspäiväkirjojen avulla. Salibandyn yhteydessä loukkaantunut pelaaja täytti vammalomakkeen ja lisäksi tutkimuslääkäri haastatteli pelaajan.

Tutkimukseen osallistuneille 374 pelaajalle sattui 172 vammaa sarjakauden aikana. Vammojen ilmaantuvuus oli huomattavasti korkeampi kilpapeleissä (40.3 vammaa / 1000 tuntia) kuin harjoituksissa (1.8 / 1000 tuntia). Polvi (27%), nilkka (22%) ja reisi (12%) olivat yleisimmin loukkaantuneet kehon osat. Vammoista 121 syntyi äkillisesti ja 51 oli luonteeltaan rasitusvammoja. Suurin osa äkillisistä vammoista kohdistui polveen ja nilkkaan (29% ja 28%) ja noin puolet näistä äkillisistä polven ja nilkan vammoista (46% ja 59%) tapahtui ilman kontaktia toiseen pelaajaan.

Toisessa salibandyvammojen epidemiologiaa selvittävässä tutkimuksessa analysoitiin pelialustan pintamateriaalin vaikutusta vammariskiin. Aineisto perustui edelliseen tutkimukseen ja analyysissä olivat mukana pelaajat kahdelta ylimmältä sarjatasolta (n=331). Päättulosmuuttujana oli salibandyn kilpapelissä sattunut äkillinen vamma, joka aiheutti vähintään vuorokauden poissaolon urheiluharjoittelusta.

Tiedot pelialustan materiaalista (synteettinen vai parkettialusta) saatiin Suomen Salibandyliitosta. Tutkimuksen päätulos osoitti, että synteettisellä alustalla sattui kaksi kertaa enemmän äkillisiä vammoja verrattuna parkettialustaan (IRR=2.1; 95% LV 1.2-3.5). Lisäksi ilman kontaktia sattuvien ja vakavien vammojen riski oli selvästi korkeampi synteettisellä alustalla.

Edellisten kolmen tutkimuksen pohjalta suunniteltiin yhden pelikauden mittainen interventiotutkimus, joka selvitti hermolihasjärjestelmän toimintaa aktivoivan alkuverryttelyohjelman vaikutusta naispuolisten salibandyn pelaajien vammariskiin. Päävastemuuttujana oli äkillinen ilman kontaktia sattuva alaraajavamma.

Tutkimukseen osallistui 28 naisten salibandyjoukkuetta (n=457), jotka satunnaistettiin harjoitus- ja kontrolliryhmään siten, että molempiin ryhmiin tuli saman verran joukkueita eri sarjatasoilta (SM-liiga, 1.divisioona, 2.divisioona). Harjoitusryhmän joukkueet osallistuivat alkuverryttelyinterventioon, joka sisälsi juoksutekniikka-, tasapaino-, hyppely- ja lihasvoimaharjoituksia. Tulokset osoittivat, että alkuverryttelyohjelma vähensi vammojen riskiä huomattavasti. Ilman kontaktia sattuvia alaraajavammoja ilmaantui harjoitusryhmässä 66% vähemmän kuin kontrolliryhmässä (IRR=0.34; 95% LV 0.20-0.57).

Väitöskirjan viimeisessä osatyössä tutkittiin edellä mainitun alkuverryttelyohjelman vaikutuksia pelaajien räjähtävään voimaan, tasapainoon, nopeuteen ja ketteryuteen. Päätulospäämuuttujina olivat lopputestien tulokset: staattinen hyppy, esikevennyshyppy, edestakaisin hyppely, palkilla seisominen ja kahdeksikkojuoksu. Pelaajat (n=222), jotka osallistuivat sekä alku- ja lopputesteihin sisällytettiin analyysiin. Tutkimus osoitti, että harjoitusryhmän pelaajien staattinen tasapaino ja jalkojen liikenopeus paranivat merkitsevästi enemmän kuin kontrolliryhmän pelaajien vastaavat arvot.

Tämän väitöstutkimuksen tulokset osoittavat, että alaraajavammat ovat naisurheilijoilla varsin yleisiä. Naisten salibandyssä korostuvat erityisesti ilman kontaktia sattuvat polvi- ja nilkkavammat. Hermolihasjärjestelmän toimintaa aktivoivilla sekä liiketaitoja ja kehon hallintaa kehittäville harjoitteille näitä vammoja voidaan kuitenkin vähentää huomattavasti. Lisäksi nämä harjoitteet kehittävät pelaajan staattista tasapainoa sekä jalkojen liikenopeutta. Säännöllinen liiketaitoja ja kehon hallintaa kehittävä harjoittelu tulisi sisällyttää naisurheilijoiden viikoittaiseen harjoitteluun.

1. INTRODUCTION

Sports activities are considered to be beneficial to health. Positive effects of regular physical activity on risk factors of chronic diseases, such as respiratory and circulatory diseases and metabolic and musculoskeletal disorders, are well described (Berlin and Colditz 1990, Helmrich et al. 1991, Nelson et al. 1994, Pate et al. 1995, Kujala et al. 1998). On the other hand, participating in sports can also be dangerous by increasing the risk of acute and overuse injuries (Parkkari et al. 2004). Thus, encouragement of people to physical activity should parallel with efforts to make sports participation safe.

Number of sports injuries has increased considerably in Finland during the past decades (Heiskanen et al. 2004, Tiirikainen et al. 2008), and today, sports injuries are the most common injury type in our country (Tiirikainen and Lounamaa 2007). In 1980 there occurred 210 000 sports injuries among 15-74-year old Finnish population, in 1993 the number of injuries was 232 000, and in 2003 the number expanded to 338 000 (Heiskanen et al. 2004). In 2006 there were 278 000 sports injuries in Finland (Tiirikainen and Lounamaa 2007). Most of the injuries were mild (78 %) causing a significant complaint no longer than one week, yet some of the injuries (2 %) led to hospitalization (Tiirikainen and Lounamaa 2007). Lüthje and colleagues (2009) did a community-level study on sports injuries treated in an emergency department in Kuusankoski Regional Hospital, Finland. A total of 4 844 unintentional injuries took place during the 24-month period, and 414 (8.5%) of all injuries were sports-related. Sixty patients with a sports-related injury needed treatment as in-patients (Lüthje et al. 2009). Altogether, these numbers indicate sports injuries are a true problem in Finland.

Floorball is currently the third largest team sport in Finland after soccer and ice hockey: about 223 000 adult and 131 000 young recreational players play floorball as a leisure activity (National exercise survey 2006a, National exercise survey 2006b). The number of licensed competitive players in March 2009 was over 42 400, of which the proportion of women was 6400 (Lepola 2009). Previous

floorball injury studies have shown that this sports often results in injuries, the knee and ankle being the most common injury sites (Löfgren et al. 1994; Wikström and Andersson 1997, Snellman et al. 2001).

Several studies have shown that female athletes involving in running, jumping and cutting activities have a higher rate of ligament injuries than corresponding male athletes, particularly knee and ankle ligament injuries (Zelisko et al. 1982, Arendt and Dick 1995, Hewett et al. 1999, Messina et al. 1999, Gwinn et al. 2000, Agel et al. 2005, Deitch et al. 2006). Fortunately, some studies have shown that it is possible to reduce the risk of sports injuries by specific training programs, which have typically consisted of agility, balance, plyometrics and strength components (Hewett et al. 1999; Wedderkopp et al. 1999; Heidt et al. 2000; Olsen et al. 2005, Mandelbaum et al. 2005; Soligard et al. 2008). These training programs have been designed to enhance players' body control and motor skills for sports-specific rapid movements, thereby reducing the injury risk (Wojtys et al. 1996a; Hewett et al. 1996; Chimera et al. 2004; Emery et al. 2005).

However, before developing and initiating a preventive measure or program for injuries in specific sports, the epidemiology and etiology of sports injuries, including incidence, severity, mechanisms and risk factors, need to be identified (van Mechelen et al. 1992).

In this thesis all these steps in the sequence of sports injury prevention are followed to finally examine the effect of neuromuscular training on injury incidence of Finnish female floorball players.

2. REVIEW OF THE LITERATURE

2.1 Floorball

Floorball is a fast and intensive team sport that is played on a court (20 m x 40 m) surrounded by a low 50 cm high plastic board with rounded corners. The playing surface can consist of wood (parquet) or artificial materials (plastic covering). Floorball goals are 160 cm (w) x 115 cm (h) x 60 cm (d) in size (Finnish Floorball Association 2007). Each of the opposing teams consists usually up to 20 players, and six of the players are on the court at the same time: three forward players, two defensive players, and a goalkeeper.

Goalkeepers wear a helmet and mask, a long-sleeved goalkeeper's shirt, long pants, knee paddings, and shoes. Goalkeepers play mostly on their knees and block the ball with their hands and body. Field players wear short-sleeved shirt, shorts, knee-high socks, and indoor shoes. Field players use graphite compound sticks (80-110cm). The ball (Ø 72 mm) is made of plastic and has 26 holes in it (Finnish Floorball Association 2007).

Standard game length is 3 x 20 min with two 10 min intermissions. Substitutions are permitted at any time during the course of the game. On average field players perform for 20 minutes of 60 minutes game. A typical play interval on the court lasts 20-120 seconds and is repeated 14-27 times in a game (Hokka 2001). The game can be characterized by interval running in different directions, sudden speed-ups, stops and turns, and under these quick-moving situations field players need to handle stick and ball: i.e. running with the ball, protecting the ball, passing the ball, receiving the pass, faking and shooting.

2.2 Epidemiological aspects of sports injuries

2.2.1 Occurrence and severity

Sports injuries are continuously increasing health problem in Finland (Kujala et al. 1995, Parkkari et al. 2004). Annual number of sports related injuries is over 330 000 (Heiskanen et al. 2004). Parkkari et al. (2004) investigated injury risk in various sports and activities in Finnish population (aged 15 to 74 years) in a one-year prospective cohort study. According to the absolute number of injuries in recreational and competitive sports, recreational walking had the largest number of injuries. But when assessing the number of injuries per 1000 hours of participation, the injury incidence was highest in squash, orienteering, and contact and team sports (Table 1).

Table 1. Participation of the representative Finnish population cohort (n=3055) to recreational and competitive sports, and absolute number of their sports injuries during a one-year follow-up period and injury incidence per 1000 hours of participation (adapted from Parkkari et al. 2004)

Sports	No of respondents	No of injuries	Injuries / 1000 hrs
Squash	27	17	18.3
Judo	11	15	16.3
Orienteering	20	5	13.6
Rinkball	41	22	11.5
Floorball	249	139	10.9
Wrestling	8	5	9.1
Basketball	59	30	9.1
Soccer	191	85	7.8
Ice hockey	82	55	7.5
Volleyball	123	55	7.0
Karate	18	11	6.7
Finnish baseball	58	20	6.6
In-line skating	262	50	5.0
Tennis	85	16	4.7
Badminton	180	25	4.6
Motor sports	35	9	4.5
Downhill skiing	187	36	4.1
Track and field sports	22	7	3.8
Equestrian sports	64	35	3.7
Running	747	92	3.6
Skating	115	9	3.3
Aerobics, gymnastics	622	75	3.1
Gym training	514	96	3.1
Cycling	1570	98	2.0
Pole walking	346	19	1.7
Crosscountry skiing	759	51	1.7
Rowing	77	4	1.5
Walking	2431	218	1.2
Swimming	1103	26	1.0
Dancing	1790	42	0.7
Golf	57	2	0.3

These statistics indicate that the absolute numbers of sports injuries might give an incorrect estimate of the actual injury risk. Therefore, the exposure of athletes needs to be taken into account to assess the injury incidence and risk in a given sports. The most accurate exposure record is based on exact individual exposure time separating the training and competition hours from each other (de Lões 1997, Fuller et al. 2006).

Incidence and severity of injuries varies between studies because of the different injury definitions and classifications, and varying study designs and methods. In general, a sports injury is defined as a physical damage occurring during sporting activities (Lüthje et al. 1996, Fuller et al. 2006, Jacobson and Tegner 2007). Sports injuries can be separated in acute and overuse injuries: an acute injury is an injury with sudden trauma (Jacobson and Tegner 2007), whereas an overuse injury can be described as a pain syndrome of the musculoskeletal system, where symptoms appear during sporting activities at previously symptom-free body part (Orava 1980).

The most prevalent definition of injury is based on time-loss from sports participation (Ekstrand and Gillquist 1983a, Wikström and Andersson 1997, Jacobson and Tegner 2007). In some studies, a sports injury is defined as an injury occurring during sports and causing a significant complaint to the subject, but not necessarily time-loss from the sports in question (Requa et al. 1993, Snellman et al. 2001, Parkkari et al. 2004). In some other studies, the definition is confined to injuries treated at a hospital or other medical facility (DeHaven and Lintner 1986, Ferretti et al. 1992, Löfgren et al. 1994).

Injury severity is usually described according to the length of time-loss from sports participation (Ekstrand and Gillquist 1983b, Fuller et al. 2006, Jacobson and Tegner 2007). However, severity of injuries can also be based on other criteria: i.e. nature of sports injury, duration and nature of treatment, time-loss from work, permanent damage, or costs of injury (van Mechelen 1997, Requa and Garrick 1996).

2.2.1.1 Incidence and severity of floorball injuries

Only few previous studies have investigated epidemiology of floorball injuries. Löfgren and colleagues (1994) analyzed Swedish players who came to the first aid station during 1990 and 1991. A total of 206 floorball injuries were registered during the two years. 28 of these occurred in games giving an approximate injury incidence of 2.4 per 1000 game hours.

Wikström and Andersson (1997) investigated prospectively the risk of acute and overuse injuries among Swedish floorball players (n=457) during one season from September 1993 to March 1994. During the study period players sustained 58 injuries and the total injury rate was 2.5 per 1000 training and game hours for female players, and 2.6 for male players.

Snellman and others (2001) examined, in turn, the incidence, nature, causes and severity of floorball injuries among Finnish players (n=295) during the 12-month period from June 1997 to May 1998. Players sustained 120 injuries during the study period. The injury rate was very low during practice (1.0 per 1000 training hours for both sexes), but quite high in games (15.9 per 1000 game hours for females and 23.7 for males).

Severity of floorball injuries was classified in different ways in the above noted three studies. Löfgren et al. (1994) analysed the injured floorball players who came to the first aid station. Severity of injuries was categorized by the Abbreviated Injury Scale (AIS) (International Injury Scaling Committee 1990) including the most severe cases only. 79% of injuries were minor (AIS 1, such as fracture of a finger or sprain of the ankle) and 21% were moderate (AIS 2, such as rupture of ACL of the knee or rupture of the Achilles tendon).

Wikström and Andersson (1997) found that 36% of the injuries were minor (time-loss 1-7 days), 29% were moderate (8-30 days), and 35% were severe (>30 days). In Snellman et al's study (2001), the severity of injury was classified into four levels according to Requa et al. (1993). 13 % of injuries caused a subjective symptom or pain (Level I), 40% of injuries resulted in modifying intensity or duration of sports activities (Level II), 24% caused a missing from training or game at least once (Level III), and 23% caused a missing from work or study at least one day (Level IV).

2.2.1.2 *Ankle and knee ligament injuries in sports*

Ankle sprain is one of the most common sports-related injuries worldwide (Yeung et al. 1994, MacAuley 1999, Fong et al. 2007, Nelson et al. 2007), and incidence of ankle sprains is especially high in team sports in which players frequently jump and land or make rapid cutting maneuvers (Lanese et al. 1990, Bahr and Bahr 1997, Hickey et al. 1997, Wedderkopp et al. 1997, Murtaugh 2001, Hinton et al. 2005, Ramirez et al. 2006, Langevoort et al. 2007, Shankar et al. 2007, Kofotolis et al. 2007, Junge and Dvorak 2007). Ankle sprains are also common in floorball: 20-35% of all acute floorball injuries involve ankle ligaments (Wikström and Andersson 1997, Snellman et al. 2001).

Another commonly injured site in sports activities is the knee joint (DeHaven and Lintner 1986, Lanese et al. 1990, Requa et al. 1993, Lüthje et al. 1996, Messina et al. 1999, Hinton et al. 2005, Hägglund et al. 2005, Deitch et al. 2006, Ramirez et al. 2006). Especially, severe knee joint injuries are a problem in sports (Arendt and Dick 1995, Myklebust et al. 1998, Agel et al. 2005, Bradley et al. 2008, Rochcongar et al. 2009). These injuries cause a long absence from sports, are costly (Cumps et al. 2008, Gianotti et al. 2008), and increase remarkably the risk for posttraumatic degenerative joint disease (Deacon et al. 1997, Larsen et al. 1999, Myklebust et al. 2003, Thelin et al. 2006, Lohmander et al. 2007).

Like ankle sprains, knee injuries are especially frequent in pivoting and cutting sports (Ekstrand and Gillqvist 1982, Wedderkopp et al. 1997, Natri et al. 1999, Giza et al. 2005, Hinton et al. 2005, Ramirez et al. 2006, Shankar et al. 2007, Borowski et al. 2008, Rochcongar et al. 2009), and floorball is one of these high risk sports including repeated accelerations, decelerations and twisting turns. In the study of Snellman et al. (2001) the knee was the most frequently injured site (22% of all injuries) among Finnish floorball players.

2.2.2 Injury mechanisms

Acute injury may result via contact or non-contact mechanism. The non-contact injury is an injury that occurs in absence of contact with another person or object. This information about injury circumstances is as relevant as precise biomechanical description of the injury mechanism.

For example, in biomechanical terms a knee injury in floorball could be described as a result of excessive valgus moment at footstrike. However, the true cause for this injury may have arisen from a contact situation with another player or object, such as tackle, tripping, stepping on a blade or a ball. Thus, the exact chain of events resulting in injury must be clarified for understanding the causes of any particular injury. Based on this exact information, it is then possible to choose and initiate appropriate methods for injury prevention.

2.2.2.1 Mechanisms of knee ligament injuries

The knee consists of the tibiofemoral and patellofemoral joints. The ligamentous structures of the knee provide static stabilization to the knee joint, control normal joint kinetics, and prevent joint displacement and abnormal rotations that may damage articular structures (Beynnon and Johnson 2003). Knee ligament injuries are common in pivoting and cutting sports, where the joint capsule, ligaments and meniscus are vulnerable to injury by sudden and forceful sports maneuvers.

One of the most common ligamentous knee injuries is ACL rupture (Boden et al. 2000, D'Amato and Bach 2003). Most ACL injuries are non-contact injuries sustained at foot strike with knee close to full extension during a sudden deceleration prior to changing direction or landing maneuver (Ireland 1999, Boden et al. 2000, Krosshaug et al. 2007). The major contributor to ACL loading during these maneuvers is the anterior tension force at the knee joint, while the knee valgus, varus or internal rotation, as well as the strong quadriceps contraction, small knee flexion angle or ground reaction force may increase hazardously the loading (Yu and Garrett 2007).

Olsen and colleagues (2004) describe two main mechanisms for ACL injury: the most common mechanism occur at plant-and-cut movement with an excessive valgus and external or internal rotation with extended knee. The other mechanism is a one-legged landing with above noted knee valgus, rotation and extension movements. Ireland (1999) termed these injurious situations as 'a position of no return' intending that at the moment of injury the muscle groups that normally control the lower limb alignment have shut down. Accordingly, knee valgus motion

is often a result of uncontrolled trunk, pelvis and hip position at cutting or landing moment.

The recent study of Boden et al. (2009) suggest that at the moment of ACL rupture subjects show a more flatfooted landing and more hip flexion than uninjured controls during similar maneuver. These ankle-related findings may indicate that the inadequate calf muscle activation results to the greater ground reaction force, which affects directly the knee.

The PCL provides a restraint to posterior translation and external rotation of the tibia. Tension of PCL increases with knee flexion and therefore this ligament is most often injured by a blow to the front tibia of the flexed knee. Another common mechanism for this injury is forced hyperflexion of the knee, for example when an athlete falls on a flexed knee with the foot in plantar flexion. (Giffin et al. 2003.)

Main functions of meniscus are shock absorption and knee stabilization, and the load on meniscus increases with the knee flexion angle during weight-bearing. Typical injury situations in sports are sudden change in direction, forceful squatting, or excessive twisting, valgus, varus or hyperextension forces to the knee. Injuries to meniscus are often combined with ACL injuries: lateral meniscal tears occur mostly with acute ACL ruptures and medial meniscal injuries occur mostly with chronic ACL insufficiency. (Urquhart et al. 2003.)

The medial and posterolateral ligamentous structures of the knee are also important for knee joint stability. The main function of the medial collateral ligament is to provide restraint to valgus and external rotation of the tibia. Medial ligament sprains can occur by non-contact valgus or rotational mechanism in cutting situation or a direct blow to the lateral side of the knee. Minor sprains of these structures can occur alone, whereas more severe injuries seem to appear as concurrent ACL injuries. (Indelicato and Linton 2003.)

The lateral collateral ligament and other posterolateral structures of the knee joint resist varus loads, external tibial rotation and posterior tibial translation near full knee extension. Injuries of this complex can result from excessive varus forces, external tibial rotation or hyperextension, and these injuries are mainly in combination with ACL or PCL ruptures. (Larson and Tingstad 2003.)

A key component of the knee extension is the patellofemoral joint which consists of the patella that articulates with the femur. The patella is a multifaceted and flat sesamoid bone inside the complex of quadriceps and patellar tendons (the extensor

tendons of the knee). In a normal knee, the patella glides smoothly over the femoral groove stabilizing and redirecting the quadriceps force as the knee is flexed. In addition, the patella magnifies the extension force by transmitting quadriceps force to the patellar tendon. In other words, the quadriceps muscle group uses the patella as a fulcrum during extension producing compressive patellofemoral joint reaction force on the articular cartilage. (Beynnon and Johnson 2003, Cone 2003.)

Static stabilizers of patella consist of analogous ligamentous structures on both lateral and medial side. Especially the medial ligamentous structures, including medial patellofemoral, medial patellomeniscal and medial patellotibial ligaments, are significant restraints to incorrect lateral translation of the patella. The typical mechanism of patellar dislocation is a twisting motion of a flexed and internally rotated knee on a fixed foot. As an end result, patella is pulled laterally out of the groove causing ruptures on the ligamentous structures of the medial side. (Cone 2003, Diehl and Garrett 2003.)

2.2.2.2 *Mechanisms of ankle ligament injuries*

The ligaments of the ankle are usually divided in the following parts: the lateral ankle complex, the medial (deltoid) ankle complex, and the tibiofibular ligaments (ligaments of the syndesmosis) (Renström and Konradsen 1997, Smith and Gilley 2003). These structures form the static stabilization of the ankle joint, while the active stability depends on muscular function. Ankle ligaments are frequently injured during sports and recreational activities, and these injuries can be divided into lateral ankle sprain, medial ankle sprain, ankle syndesmosis sprain, and dislocation of the ankle without fracture (Casillas 2003).

The most commonly injured site of ankle and foot complex are the lateral ligaments (Renström and Konradsen 1997). The three fibular collateral ligaments, the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL), are generally known as the lateral ligaments (Smith and Gilley 2003). The ATFL is considered the weakest and most frequently injured ligament of the ankle (Casillas 2003, Smith and Gilley 2003).

The most common mechanism causing lateral ankle sprain is a touchdown situation where ankle is inverted, plantarflexed, and supinated (Renström and

Konradsen 1997). This sudden and forceful inversion may be caused by extrinsic factor, such as bumpy surface or stepping on other players' foot, but frequently these injuries occur in non-contact circumstances as a result of poor control of ankle and foot. Incorrect foot position at touchdown may be a result of joint instability, poor position sense, or altered muscle activation because of previous ankle sprain (Delahunt et al. 2006, Delahunt et al. 2007, Van Deun et al. 2007).

The medial ligaments of ankle, or the deltoid ligament complex, are less commonly torn than the lateral ones. The medial ankle sprain is commonly caused by excessive eversion or twisting movement (Casillas 2003, Smith and Gilley 2003). The forceful eversion can be caused by external factor, such as irregular surface, and twisting force may be a result of high friction between the shoe and surface.

2.2.3 Risk factors

2.2.3.1 *General risk factors for sports injuries*

Sports injuries result from a complex interaction of multiple risk factors and events (Figure 1). Risk factors are traditionally divided into two main categories: extrinsic and intrinsic risk factors (Lysens et al. 1984, Taimela et al. 1990, van Mechelen 1992, Meeuwisse 1994, Bahr and Holme 2003) (Table 2).

Extrinsic risk factors relate to environmental variables such as the level of play, exercise load, position played, field conditions, and equipment. Intrinsic risk factors relate to the individual characteristics of a subject such as age, gender, previous injury, anthropometrics, neuromuscular performances, and alignment. The final element in the chain of causation is an inciting event, such as tackle or failed landing, at the onset of injury (Meeuwisse 1994).

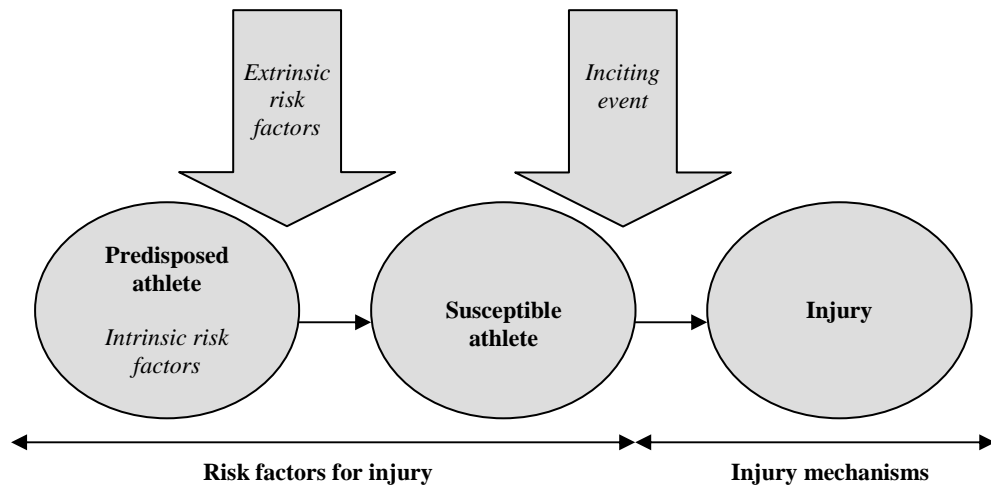


Figure 1. A multifactorial model of sports injury etiology (adapted from Meeuwisse 1994)

Table 2. Extrinsic and intrinsic risk factors for sports injuries (adapted from van Mechelen 1992)

Extrinsic risk factors	Intrinsic risk factors
Type of sports	Age
- <i>Type, amount, frequency and intensity of physical loading</i>	Gender
- <i>Rules</i>	Height
Nature of event	Weight
- <i>Competition or practice</i>	Body fat
- <i>Level of competition</i>	Joint stability / mobility
Exposure time	Previous injury
Human factors	Anatomic abnormalities
- <i>Role of opponents, team mates, coaches and referees</i>	Physical fitness
Type of surface	- <i>Aerobic endurance</i>
Lightning	- <i>Muscle strength, tightness, weakness</i>
Weather conditions	- <i>Speed, reaction time</i>
Time of season	- <i>Motor abilities, sporting skills, coordination</i>
Sporting tools	- <i>Flexibility</i>
- <i>Stick, ball</i>	Psychological profile
Protective equipment	- <i>Personality</i>
Other equipment	- <i>Self-concept</i>
- <i>Shoes, clothing</i>	- <i>Risk acceptance</i>
	- <i>Stress coping</i>

Type of sport

Nature of sport has a strong influence on injury risk (Backx et al. 1989, Mihata et al. 2006). Moreover, the risk of injury may differ within a certain sport resulting from different playing positions (Faude et al. 2006). The injury rate increases with the intensity of the activity (Requa et al. 1993, Parkkari et al. 2004) and with the frequency of contacts during the sports (Backx et al. 1991, van Mechelen et al. 1996).

External loading of the joints of the lower extremity is considerably larger during sidestepping and crossover maneuvers compared with normal running (Besier et al. 2001), and therefore, the risk of ligament injuries is higher in cutting and pivoting sports. In team sports the injury incidence is higher during games than practice (Backx et al. 1989, Engström et al. 1991, Kujala et al. 1995, van Mechelen et al. 1996, Messina et al. 1999, Snellman et al. 2001, Borowski et al. 2008), though players spend far more time in training than games.

Shoe-surface interface

Shoe-surface interaction has been implicated as a risk factor for sports injury. In sports, adequate friction properties are needed for avoid slipping and slipping related injuries. Optimal ranges of friction permits athletes shoe to grip a surface better, and furthermore this makes movements faster. On the other hand, if friction between shoe and playing surface is excessive, especially in sports with high impacts and fast and twisting turns, overload in joints may increase the risk of acute and overuse injuries (Nigg and Segesser 1988, Ekstrand and Nigg 1989, Heidt et al. 1996, Livesay et al. 2006, Villwock et al. 2009).

Powell and Schootman (1992) showed that among elite football players incidence of knee ligament injuries was higher on artificial turf compared to natural grass. Likewise, Arnason et al. (1996) found increased injury incidence on artificial turf in elite soccer players. Myklebust and colleagues (1997) investigated the incidence of ACL injuries among male and female handball players, and suggested that 55% of those injuries were friction related. In the study of Olsen and others (2003) the ACL injury rate was higher on artificial floor than on wooden floor in female handball

players, but in male players there were no differences in injury rates between these two different surfaces.

It is also speculated that frequent use of hard surfaces may produce sports injuries (Nigg and Segesser 1988, Ekstrand and Nigg 1989). High impact forces, which are related to the hardness of surface, can cause overload on human collagen tissues such as bone, cartilage, ligament and tendon. The critical limit for overloading is tissue-and subject-specific, but if a single excessive impact force or repeated sub-intense impact force exceed the limit, tissue damage may occur (Ekstrand and Nigg 1989).

Age

Age is also a risk factor for sports injuries, partly due to increased frequency and intensity within training and competitions in adult athletes compared to adolescents. Backous and colleagues (1988) investigated occurrence of soccer injuries among young players (aged 6-17 years), and they found that injury risk doubled after age 14. In the study of Stevenson et al. (2000), the injury risk was higher among athletes aged 26-30 compared to younger and older athletes. Parkkari and others (2004) founded that injury incidence per exposure time was highest in 15-24-year-old recreational and competitive athletes, and after that it decreased in both sexes. In a recent study of sports injuries treated in Finnish hospital emergency department, the median age of injured patients was 25 years, and the injury rates were highest between ages 10 and 19 years (Lüthje et al. 2009).

Gender

Sex does not seem to be an important risk factor for all type of injuries, but when considering injuries in lower extremities, especially knee and ankle injuries, female athletes seem to have a higher risk in certain sports. Girls and boys have an equal number of ligament injuries during childhood, but immediately after growth spurt injury rate increases clearly among girls (Tursz and Crost 1986).

Several studies have found that female athletes, who participate in the pivoting and cutting sports, have a higher risk for ankle sprains (Zelisko et al. 1982,

Wikström and Andersson 1997, Beynnon et al. 2005b) and knee injuries (Zelisko et al. 1982, Arendt and Dick 1995, Hewett et al. 1999, Messina et al. 1999, Gwinn et al. 2000, Agel et al. 2005, Deitch et al. 2006) than do males participating in the same sports. Especially the risk of ACL injuries (Myklebust et al. 1998, Arendt et al. 1999, Agel et al. 2005), meniscus or cartilage tears (Arendt and Dick 1995) and patellofemoral disorders (DeHaven and Lintner 1986, Arendt and Dick 1995, Arendt and Griffin 2000) is significantly higher in females than males in similar sports and training level.

The reasons for increased risk of ligament injury in female athletes are multifactorial, the most common explanations including anatomical, hormonal and neuromuscular factors (Hutchinson and Ireland 1995, Harmon and Ireland 2000, Hewett 2000, Henry and Kaeding 2001, Ireland 2002, Hewett et al. 2004). Sex hormones-related increase in ligament laxity and joint looseness, as well as the neuromuscular factors, such as decreased coordination and muscle activation, may partly explain the increased occurrence of ligament injuries in females.

Physical condition and motor abilities

Fitness level and motor abilities have been suggested to be notable factors influencing in sports injury risk (Haycock and Gillette 1976). It is a well-known fact that aerobic fitness level contribute to the risk of injury, since fatigue reduces coordination and dynamic muscle control (Wojtys et al. 1996b, Chappell et al. 2005, Thorlund et al. 2008). Some studies have also shown that certain training related neuromuscular deficiencies, such as lack of strength, delayed muscle firing, defective muscle activation order, and muscle imbalances, associate with injury risk (Ekstrand and Gillquist 1983a, Baumhauer et al. 1995, Hewett et al. 1999, Söderman et al. 2001, Nadler et al. 2002, Leetun et al. 2004, Zazulak et al. 2007).

Those above noted neuromuscular limitations have a direct influence on neuromuscular control during sports maneuvers. Incorrect technique and inability to control the position and motion of the body in integrated sports activities are associated with increased risk of acute and overuse injury (Ireland 2002, Hewett et al. 2005, Kibler et al. 2006, Souza and Powers 2009).

A failure of motor control may be due to various factors, for example joint instability, previous injury, inadequate training and poor condition, as well as deficiencies in nutrition and fluid intake. There is strong evidence that previous injury, particularly when followed by inadequate rehabilitation, may lead to neuromuscular deficiencies and incur an athlete to an increased risk for re-injury (Ekstrand and Gillquist 1983b, Lysens et al. 1984, Milgrom et al. 1991, Requa et al. 1993, Surve et al. 1994, Bahr and Bahr 1997, McKay et al. 2001, Hägglund et al. 2006). In the same way, numerous studies have proved that dehydration and sweat loss decrease sports performance, induce fatigue and increase the risk of sports injury (Bergeron 2003, von Duvillard et al. 2004).

2.2.3.2 Risk factors for knee ligament injuries

The knee joint is the largest and most complex joint of a kinetic chain, and other anatomical sites, including the trunk, hip and ankle, may contribute to knee injury (Ireland 2002, Trimble et al. 2002, Zazulak et al. 2007). In other words, the mechanical alignment of the knee itself (Kujala et al. 1987) or other parts of lower extremity and trunk influences to the function and stability of the knee joint.

Several studies have suggested that anatomical variations, such as increased anterior pelvic tilt, greater genu recurvatum (hyperextensibility of the knee joint), increased femoral anteversion (the femoral neck is leaned forward, that causes internal rotation of the femur), and greater quadriceps (Q) angle, may be partly associated with knee injury (Bonci 1999, Reider et al. 2003, McKeon and Hertel 2009).

Small anterior pelvic tilt is normal, but excessive one can lead to postural dysfunction. As the pelvis is positioned forward and downward, the lordosis of the low back increases and the femurs (thigh bones) rotate inward, causing an increased stress on the knee joints.

The Q angle is formed between two lines: one from anterior superior iliac spine through the center of the patella, and a second from the tibial tuberosity through the center of the patella (Calmbach and Hutchens 2003). An abnormally large Q-angle can lead to knee problems, such as patellofemoral pain. Women have a relatively wider pelvis than men that could increase significantly the Q angle in some subjects

(Woodland and Francis 1992). Shambaugh et al. (1991) found that the mean Q angles of basketball players sustaining knee injuries (14°) were significantly larger than mean Q angles for the uninjured players (10°).

The substantial factor in knee ligament injuries seems to be the position of the lower extremity during the injury. The excessive degree of static and dynamic knee valgus has been viewed as hazardous for knee ligaments, particularly for the ACL (Ford et al. 2003, Olsen et al. 2004, Ford et al. 2005, Hewett et al. 2005).

Some studies suggest that excessive foot pronation may influence to the incidence of knee injury by increasing internal tibial rotation (Woodford-Rogers et al. 1994, Bonci 1999, Allen and Glasoe 2000). Uhorchak et al. (2003) suggest that increased BMI is associated with knee injury. Also, the difference in total volume and geometry of ACL, as well as small size of the femoral notch may have a contribution to ACL injury risk (Souryal and Freeman 1993, Shelbourne et al. 1998, Uhorchak et al. 2003, Chaudhari et al. 2009).

Female hormones have an important role in the regulation of collagen synthesis and degradation (Dubey et al. 1998, Yu et al. 1999). Decreased ligament strength due to cyclic changes in sex hormones could be a contributor to ligament injury risk (Möller Nielsen and Hammar 1991, Wojtys et al. 1998, Arendt et al. 1999, Wojtys et al. 2002, Beynnon et al. 2006, Park et al. 2009), but the findings from different studies have been contradictory: the phase of the menstrual cycle where ligament laxity and injury rate increases diverse between the studies (Zazulak et al. 2006).

The general joint laxity is larger in females compared to males (Beynnon et al. 2005a). Joint laxity affects both hyperextension and valgus motion of the knee, which can strain the ACL (Uhorchak et al. 2003, Hewett et al. 2005, Myer et al. 2008). Also, increased hamstring flexibility may be partially involved for the decreased dynamic control of the knee in female athletes (Huston and Wojtys 1996, Boden et al. 2000).

Overall, the neuromuscular control seems to be the most important factor to the knee ligament injury risk. Deficits in proprioception, strength, and timing of muscle activation (Kennedy et al. 1982, Schultz et al. 1984, Hewett et al. 1996, Huston and Wojtys 1996, Rozzi et al. 1999, Ford et al. 2003, McLean et al. 2004, Pflum et al. 2004, Hewett et al. 2005, Zazulak et al. 2005, Kiriya et al. 2009) are proved to be related to altered movement patterns, altered activation patterns and inadequate muscle stiffness during sports maneuvers. However, neuromuscular imbalances, due

to previous injury, immobilization, deficient training, developmental differences or hormonal influences, are alterable by using specific neuromuscular training regularly.

Hewett and co-workers (2001) have presented that there exist three main neuromuscular imbalances in female athletes predisposing to knee injury: ligament dominance, quadriceps dominance and leg dominance. *Ligament dominance* means that an athlete allows the knee ligaments to absorb the ground reaction force during sports maneuvers – in other words, she controls the knee joint by ligaments rather than by lower extremity musculature.

With *quadriceps dominance* a female athlete tends to first activate her knee extensor muscles over knee flexor muscles during high force situations. Hewett et al. (1996) reported that hamstring activity was three-fold higher in male athletes compared to female athletes. This deficit of muscular co-contraction limits directly the potential to protect knee ligaments.

Leg dominance is the imbalance between opposite extremities. Side-to-side differences in strength, flexibility and coordination have been proven to be important risk factors for knee injury (Knapik et al. 1991, Hewett et al. 1996, Hewett et al. 1999).

2.2.3.3 Risk factors for ankle ligament injuries

The leading risk factor for ankle sprain is a previous ligament injury involving the same ankle (Milgrom et al. 1991, Bahr and Bahr 1997, McKay et al. 2001, McGuine and Keene 2006, McHugh et al. 2006, Trojian and McKeag 2006, Tyler et al. 2006, Kofotolis et al. 2007). Bahr and Bahr (1997) suggested that athletes who have sustained an ankle sprain within the previous 6-12 months have 10-fold higher risk to ankle sprain than those without previous injury.

Casillas (2003) presents that mostly cited risk factors for lateral ankle sprains are generalized ligamentous laxity, inappropriate shoe-wear, irregular playing surface, and cutting activity. In addition, some studies have found that decreased dorsiflexion of the ankle, increased postural sway (or poor balance), inadequate proprioception (Payne et al. 1997, McGuine et al. 2000, Willems et al. 2005a,

Willems et al. 2005b, Trojian and McKeag 2006), as well as the body mass index (BMI) predicts the ankle sprain (Milgrom et al. 1991, McHugh et al. 2006, Tyler et al. 2006).

For the female athletes, increased tibial varum and calcaneal eversion range of motion are associated with ankle ligament injury, whereas for the male athletes, the risk of injury is higher with increased talar tilt (Beynnon et al. 2001). One of the essential risk factors for ankle injury is the inability to control the accurate position of foot prior to touchdown. Excessive supination or plantarflexion of the foot as it touches the ground increases the risk of ankle ligament injury (Renström and Konradsen 1997, Wright et al. 2000).

2.3 Injury prevention

Sports injury research and prevention has been recommended to follow a mode of four steps (van Mechelen 1992) (Figure 2). Firstly, the sports injury problem must be defined in terms of the incidence and severity. Secondly, the risk factors and mechanisms underlying the occurrence of sports injuries must be identified. From this information on the risk factors, the third step is to introduce measures that are likely to reduce risk or severity of sports injuries. Finally, the effectiveness of the introduced preventive measure must be evaluated by repeating the first step, or preferably by performing a randomized controlled trial.

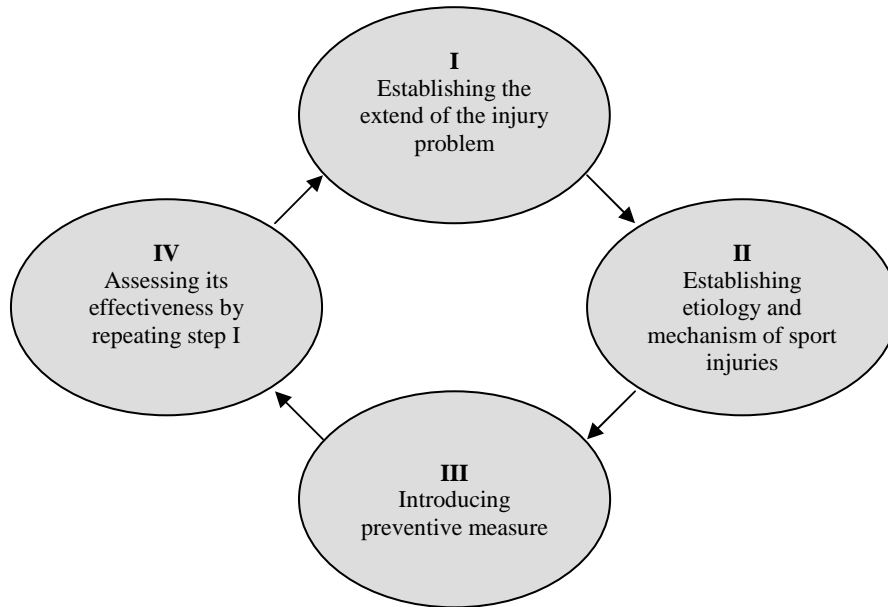


Figure 2. The sequence of prevention of sports injuries (adapted from van Mechelen 1992)

In short, we need to know whether injuries are a substantial problem in certain sports, and if so, whether there are factors that can be modified or changed in order to control the problem. There are several risk factors that can be changed or modified, like sports equipment, contents and amount of training, personal skills and physical condition. However, some of the predisposing factors, such as age, gender, anatomic abnormalities, previous injury, weather conditions, and type of playing surface are more difficult to change or even completely unchangeable.

2.3.1 Neuromuscular training programs

In early 1980's Ekstrand and co-workers (1983c) did the pioneer study of soccer injury prevention and they found that with a multiform program including warm-up, stretching, use of leg guards, ankle taping, and systematic rehabilitation the injury rate in male soccer players could be reduced 75 %. Especially, the risk of ankle and knee ligament injuries was significantly lower in the intervention group.

During the past decade, several research groups have investigated if it is possible to prevent sports injuries using specific training programs, which include neuromuscular training, e.g. balance board, strengthening, agility and plyometric exercises (Tropp et al. 1985, Hewett et al. 1999, Wedderkopp et al. 1999, Heidt et

al. 2000, Söderman et al. 2000, Junge et al. 2002, Verhagen et al. 2004, Emery et al. 2005, Olsen et al. 2005, Mandelbaum et al. 2005, McGuine and Keene 2006, Soligard et al. 2008). A considerable number of these studies have shown that regular training can reduce 17-80 % of injuries, whereas few of them have found no decline in risk of injury in the intervention group (Table 3). However, a problem in interpreting these results is that the methodological quality of the interventions has been heterogeneous (Aaltonen et al. 2007).

The training programs for injury prevention have been designed to enhance balance and body control, motor skills and performance properties, and thereby improve lower extremity biomechanics and reduce injurious forces. The main outcome on injury prevention studies has been incidence of injuries. However, few studies have also measured the training effects on athletes' performance, and they have shown that neuromuscular training, designed to prevent injuries, is likely to enhance musculoskeletal performance, for example proprioception, balance, muscle activation and power (Hewett et al. 1996, Wojtys et al. 1996a, Chimera et al. 2004, Emery et al. 2005, Chappell and Limpisvasti 2008, Panics et al. 2008).

Table 3. Characteristics of sports injury studies including preventive training program

Reference	Study type	Sport or activity	Intervention	Duration	Sex, age	No. of participants (group)	Outcomes	OR/RR (95% CI)
Tropp et al. (1985)	RCT	Soccer	Balance board training	6 mo	M NR*	144 (intervention) 171 (control)	Ankle sprains	OR 0.24 (0.10-0.57)
Wedderkopp et al. (1999)	RCT	Handball	Balance board training and functional exercises	10 mo	F 16-18	111 (intervention) 126 (control)	Sports injuries	OR 0.20 (0.10-0.41)
Hewett et al. (1999)	Prospective intervention study	Basketball, volleyball and soccer	Preseason training (6-wk): plyometric, landing technique, strengthening, and flexibility exercises	1 yr	F+M HS**	366 (F intervention) 463 (F control) 434 (M control)	Serious knee injuries	RR 0.25 (0.06-1.15)
Heidt et al. (2000)	RCT	Soccer	Preseason training (7-wk): endurance, strength, plyometric, and flexibility exercises	1 yr	F 14-18	42 (intervention) 258 (control)	Sports injuries	RR 0.42 (0.2-0.9)
Söderman et al. (2000)	RCT	Soccer	Home-based balance board training	7 mo	F 15-25	121 (intervention) 100 (control)	Lower limb injuries	OR 1.25 (0.62-2.52)
Junge et al. (2002)	Prospective intervention study	Soccer	Multi-intervention: warm-up, cool-down, rehabilitation, taping, fair play, and strength, endurance, coordination, stability, and flexibility exercises	1 yr	M 14-19	101 (intervention) 93 (control)	Sports injuries	RR 0.73

Reference	Study type	Sport or activity	Intervention	Duration	Sex, age	No. of participants (group)	Outcomes	OR/RR (95% CI)
Verhagen et al. (2004)	RCT	Volleyball	Balance board training	36 wk	F+M 21-27	641 (intervention) 486 (control)	Ankle sprains	New sprains RR 0.8 (0.3-2.2) Recurrent sprains RR 0.4 (0.2-0.8)
Emery et al. (2005)	RCT	Physical education students	Home-based balance board training	6 mo	F+M 14-19	66 (intervention) 61 (control)	Sports injuries	RR 0.2 (0.05-0.88)
Olsen et al. (2005)	RCT	Handball	Structured warm-up program: technique, strengthening, balance, and plyometric exercises	8 mo	F+M 15-17	958 (intervention) 879 (control)	Ankle and knee injuries	RR 0.53 (0.35-0.81)
Mandelbaum et al. (2005)	Prospective intervention study	Soccer	Warm-up program: running, stretching, strengthening, plyometrics, and soccer specific agility exercises	2 yr	F 14-18	<i>Year 1:</i> 1041 (intervention) 1905 (control) <i>Year 2:</i> 844 (intervention) 1913 (control)	ACL injuries	<i>Year 1:</i> RR 0.11 (0.03-0.48) <i>Year 2:</i> RR 0.26 (0.09-0.73)
McGuine & Keene (2006)	RCT	Basketball and soccer	Balance exercises on floor and balance disc	1 season	F+M HS**	373 (intervention) 392 (control)	Ankle sprains	RR 0.56 (0.33-0.95)
Soligard et al. (2008)	RCT	Soccer	Structured warm-up program: running, strengthening, plyometric and balance exercises	1 season	F 13-17	1055 (intervention) 837 (control)	Lower limb injuries	RR 0.71 (0.49-1.03)

* NR=not recorded, **HS=high school aged

2.3.2 Neuromuscular training in female athletes

During pre-pubertal years, the pace of neuromuscular development is similar in boys and girls (Hamstra-Wright et al. 2006). However, neuromuscular patterns in males and females differ essentially during maturation: males demonstrate great increases in coordination, strength, power and speed, whereas girls show only little change in these performance properties (Häkkinen 1990, Beunen and Malina 1996, Froberg and Lammert 1996, Bar-Or and Rowland 2004, Hewett et al. 2004).

For example, no gender differences in peak leg power are noted before puberty (Barber-Westin et al. 2005), but during puberty boys demonstrate significantly greater increase in muscle power (Quatman et al. 2006). In addition, boys demonstrate better neuromuscular control of the knee in late puberty than they had in early puberty, whereas the neuromuscular control of the knee decreases among girls from early to late puberty (Hewett et al. 2004).

Most of the musculoskeletal differences between males and females develop after the growth spurt. Researchers have suggested that these musculoskeletal changes that accompany maturation result in poor neuromuscular control in female athletes (Hewett et al. 2004, Hass et al. 2005, Yu et al. 2005). Concurrently, post-pubescent females suffer higher level of knee injuries when compared to the pre-pubescent females and pre- and post-pubescent males in the same sports (DeHaven and Lintner 1986, Arendt et al. 1999, Hewett 2000).

Developmental changes and gender differences in biomechanics have been investigated in different tasks, such as running, landing, and cutting. Following the onset of growth spurt, female athletes change the way of landing (Hewett et al. 2004, Hass et al. 2005, Yu et al. 2005). Female athletes demonstrate reduced knee flexion, hip flexion, hip abduction, and hip external rotation during landing compared with male athletes (Chappell et al. 2007). In addition, in contrast to males and pre-pubertal girls, adolescent girls and adult women demonstrate decreased flexor torques and hamstring-to-quadriceps peak torques (Chappell et al. 2002, Barber-Westin et al. 2006).

However, these neuromuscular imbalances and deficiencies among female are alterable. For example, Hewett and co-workers (1996) initiated a training program

that focused on correction of muscle imbalances and movement techniques in adolescent girls. The intensive six-week training program included jump, weight, and stretching exercises three times a week. One training session lasted two hours. The authors showed that young female athletes demonstrated greater dynamic knee control, increased hamstring-to-quadriceps peak torque, as well as decreased side-to-side differences and impact forces after the training period. It seems that intensive neuromuscular training induces a pronounced neuromuscular progress that would otherwise be absent in adolescent girls.

Gender differences in neuromuscular function and physical performance can be reduced also in adulthood. Females can enhance their physical performance properties even higher level than untrained males. Kraemer and colleagues (2001) showed that periodized progressive strength training results significant improvements in high-intensity physical performances over the six-month period in adult females. Subjects were randomly assigned to six training groups: 1) whole body strength and power, 2) whole body strength and hypertrophy, 3) upper body strength and power, 4) upper body strength and hypertrophy, 5) field plyometric and partner-resisted and 6) aerobic training group. Training related adaptations in one repetition maximum (1 RM) (squat, bench press, and high pull), power (squat jump and bench press throw), squat endurance and functional tests were specifically associated with the type and intensity of training program. 1 RM in weight training is the maximum amount of weight one can lift in a single repetition for a given exercise, and it can be used for measuring maximal strength.

In another study of Kraemer and colleagues (2003) showed that systematic and periodized resistance training can produce great improvements as in strength as in sports specific motor performances in adult female athletes.

Subsequently some studies have also suggested that regular neuromuscular exercises not only improve performance properties, but also reduce injurious forces (Paterno et al. 2004, Noyes et al. 2005, Myer et al. 2006) and decrease lower extremity injury risk in females. These studies have included either vigorous and heavy training programs as described above (Hewett et al. 1999, Heidt et al. 2000, Mandelbaum et al. 2005), or low-to-moderate intensity training programs (Wedderkopp et al. 1999, Emery et al. 2005, Olsen et al. 2005, McGuine and Keene 2006).

Olsen and colleagues (2005) showed that a structured warm-up program designed to improve running, cutting, and landing technique, as well as balance, motor control and strength, reduced acute ankle and knee injuries in young female handball players. The intervention teams used the warm-up program before handball training for 15 consecutive sessions and then once a week during the season. A total duration of warm-up session was 15-20 minutes.

Söderman and co-workers (2000) found no effect of balance board training on the incidence of lower extremity injuries. However, the program they used was home-based training with poor compliance and high drop out rate of players. Thus, the neuromuscular training for enhancing performance and reducing injury risk should be included in structured trainings of teams.

3. AIMS OF THE STUDY

The aims of this thesis were:

- 1 to determine the incidence of cruciate ligament injuries of the knee in adolescents and young adults in Finland (I)
- 2 to describe the incidence, nature, causes, and severity of floorball injuries in Finnish female players (II)
- 3 to analyze interaction between playing surface and injury risk in floorball (III)
- 4 to assess the effects of neuromuscular warm-up program in lower extremity injury risk (IV)
- 5 to determine the effects of neuromuscular warm-up program in muscle power, balance, speed and agility (V)
- 6 to analyze safety of neuromuscular warm-up program (IV and V)

4. MATERIALS AND METHODS

4.1 Epidemiologic studies

4.1.1 Cruciate ligament injuries (I)

4.1.1.1 Study design and participants

The first study was a population-based cohort study in Finnish adolescents and young adults with 9-year follow-up. The study population was drawn from the Finnish Population Register Center (FPRC) through the selection of all Finnish adolescents (aged 14, 16 and 18) born in a certain days.

The baseline population consisted of 50 403 subjects of whom 46 531 responded to the Adolescent Health and Lifestyle Surveys (AHLS). The proportion of females and males in this sample was 25 099 (54% of all respondents), and 21 432 (46%), respectively. The mean ages of the respondents were 14.6, 16.6 and 18.6 years. Persons who had been hospitalized with ACL or PCL injury before entering to the sample were excluded from analysis (n=73), whereas persons who died during the follow-up (n=257) were followed up until the time of death.

4.1.1.2 Outcomes and data collection

The outcome variables in this data set were ACL and PCL injuries of the knee. The data used in the study was a combined data from AHLS with data from national injury registers: the National Hospital Discharge Register (NHDR) and to the Cause-of-Death Statistics (CDS) in Finland. The AHLS is a nationwide monitoring system of adolescent healthiness in Finland, conducted as a postal survey.

A structured questionnaire including questions about background, health and health behaviours has been mailed to a large sample of Finnish adolescents on

alternate years since 1977. The diagnoses in the NHDR were coded using the 9th (1987-1995) and 10th (1996-2001) revisions of the International Classification of Diseases (ICD) (World Health Organization 1975, World Health Organization 1992).

The baseline data from AHLS for the analyses was collected from 1987 to 1997. The follow-up in the NHDR and CDS started on April 30 of each year. The end-points in the study were the date of the cruciate ligament injury hospitalization, the date of death, or the end of the study on 31 December 2001. The respondents were followed up on average 9.3 years.

4.1.2 Floorball injuries (II)

4.1.2.1 *Study design and participants*

The second study was a prospective cohort study in Finnish female floorball players with six-month follow-up. All the 374 players, mean age 24 years (range 15-52), were recruited from Finnish top leagues; the elite league, the first division, and the second division. Final participation was based on the informed consent of each player. All players who were injury and symptom free at the onset of the study were included in the study. 164 players from Finnish elite league, 183 players from first division and 27 players from second division participated.

4.1.2.2 *Outcomes and data collection*

The outcome variables in this study were all floorball-related time-loss injuries. An injury was defined as any acute injury or overuse injury occurring during a floorball game or practice and making the player unable to participate in a game or practice session during the following 24 hours.

During the floorball season 2004-2005 (six-month period) exposure time and floorball injuries were registered among the above noted players. The practice and game hours of floorball were recorded on an individual exercise diary and all injuries were registered with a structured questionnaire and verified by a physician. Training exposure was defined as structured team-based and individual physical

activities that were aimed at enhancing or maintaining players' floorball skills or physical condition. Rehabilitation exercises for injuries were not a part of training exposure. Game exposure was defined as match between two different clubs.

4.1.3 Playing surface and injury risk (III)

4.1.3.1 *Study design and participants*

The third study was a prospective cohort study in Finnish female floorball players based on the previous data set (chapter 4.1.2) with the following exception: the study population consisted of 331 female players from the two top level leagues. Their mean age was 24.5 years (range 15-52). All players who had active playing minutes in either elite league or first division were included in the study.

4.1.3.2 *Outcomes and data collection*

The outcome variables in this study were all acute time-loss injuries which occurred during official floorball games. An injury was defined as any acute injury occurring during a floorball elite league or first division game making the player unable to participate in a game or practice session during the following 24 hours.

Exposure time from floorball games was counted for both floor types: active game hours on artificial floors and on wooden floors. Game exposure was defined as official elite league or first division match between two clubs. Information on the floor type (parquet or artificial floor) at each game was given by the Finnish Floorball Association. All participating teams played on both playing surfaces during the season.

4.2 Intervention studies

4.2.1 Neuromuscular warm-up program and injury risk (IV)

4.2.1.1 *Participants and randomization*

The fourth study was a cluster randomized controlled study in Finnish female floorball players with six-month follow-up. Twenty-eight teams and 457 female floorball players, mean age 24 years (range 15-53), from Finnish top leagues participated in the study. Final participation was based on the informed consent of each player. A player was included in the study if she was an official member of participating team (licensed player) and did not have major injury at the onset of the study.

Stratified cluster randomization to the intervention teams and control teams was performed at each league level (elite league, first division and second division) using a team as the unit of randomization. Teams allocated to the intervention group (14 teams, n=256) were informed about the upcoming a warm-up program for preventing injuries. Teams in the control group (14 teams, n=201) were asked to do their usual training during the study season.

4.2.1.2 *Outcomes and data collection*

The main outcome variable in this study was an acute time-loss injury of lower extremities that occurred in non-contact circumstances (no contact with other player, stick or ball). An injury was defined as an acute non-contact injury involving lower extremities occurring during a floorball game or practice and making the player unable to participate in a game or practice session during the following 24 hours.

The secondary outcome variables were other time-loss injuries of lower extremities. Training and game exposure was based on the previous definitions (chapter 4.1.2) with the following exception: training exposure included only structured team-based physical activities, including also the intervention training.

At baseline, players completed a questionnaire about background information including anthropometrics, previous injuries, floorball experience and preseason

training volume. During the six-month study period, each team coach wrote-up players' structured practice and game hours on an exercise diary and informed about all injured players. All injuries were registered with a structured questionnaire. The study physician contacted a player after each new injury and checked the accuracy and consistency of the filled questionnaire.

In addition, the qualified warm-up instructors kept a diary about the scheduled warm-up sessions in the intervention teams. At the end of the season all players filled in a questionnaire concerning injuries and subjective participation in the study to check the completeness and coverage of data collection.

4.2.1.3 *Training program*

Teams in the intervention group participated in a structured neuromuscular warm-up program comprising comprehensive exercises. Warm-up sessions were supervised and controlled by a qualified instructor.

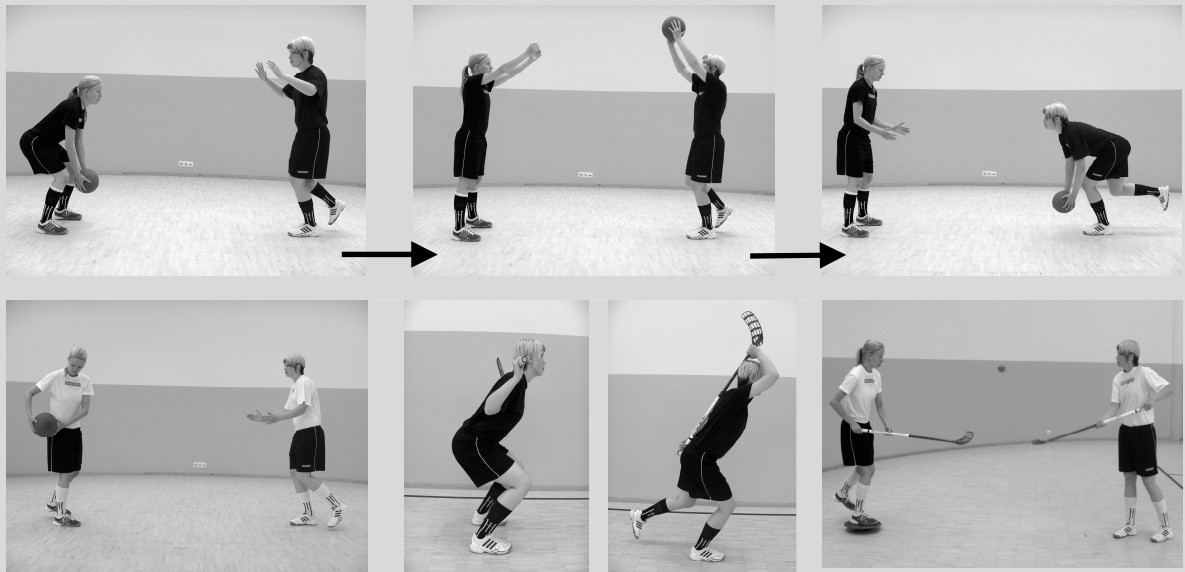
The duration of the intervention was 26 weeks, including 42 structured warm-up sessions, which lasted 20-30 minutes each. The intervention program included the following four periods during the season: the first period (3 sessions/week), the second period (>1 session/week), the third period (2-3 sessions/week), and the fourth period (>1 session/week). Intensive training with 2-3 warm-up sessions a week took place at the start of the season and during the break from games in December. Over the competitive season the warm-up exercises were followed through with maintaining principle.

The neuromuscular warm-up program consisted of four different types of exercises: 1) running technique, 2) balance and body control, 3) plyometric and 4) strengthening exercises (Table 4 and Figure 3). Each exercise type had different variations, with diverse difficulty and intensity. The warm-up sessions were carried out just before floorball exercises, with low-to-moderate intensity for each exercise type. These comprehensive warm-up exercises were specifically directed at improving the control of back, knees and ankles during sports specific maneuvers (running, changing direction, stopping, etc.), and by this means to reduce the risk of injuries. Players worked in pairs and they were guided to look each others' technique and give feedback during warm-up training.

Table 4. Neuromuscular warm-up program

I Running exercises		5-7 minutes
Each training session started with jogging (1), then three to four running technique exercises from eight different variations (2-9), and speed run (10) in the end.		
1) Jogging straight forward		2 x 20 metres back and forth
2) Carioca running		1-2 x 20 metres, return by slow jogging
3) Sideways gallop		1-2 x 20 metres, return by slow jogging
4) Zigzag running forward		1-2 x 20 metres, return by slow jogging
5) Zigzag running backwards		1-2 x 20 metres, return by slow jogging
6) Skipping		1-2 x 20 metres, return by slow jogging
7) Walking lunges x 4-8 and slow forward running		1-2 x 20 metres, return by slow jogging
8) Slow alternate bounding		1-2 x 20 metres, return by slow jogging
9) Combination hops (right-right-left-left-right-right..)		1-2 x 20 metres, return by slow jogging
10) Speed running		1-2 x 20 metres, return by slow jogging
II Balance and body control exercises		5-7 minutes
One of the following three exercises during each training session, each of these three exercise types had variations with different degree of difficulty.		
1) Squat technique with stick (either double or single leg)		
- Double leg		2-3 x 10-15 repetitions
- Single leg (right + left)		2-3 x 8-10 + 8-10 repetitions
2) Balance exercise with medicine ball		
- Single leg (right + left)		2-3 x 4-6 + 4-6 throws
3) Balance board exercise (either double or single leg)		
- Double leg: with or without stick + ball		2-3 x 20-30 seconds
- Single leg (right + left): with or without stick + ball		2-3 x 20-30 + 20-30 seconds
III Plyometric exercises		5-7 minutes
One of the following three exercises during each training session, each of these three exercise types had variations with different degree of difficulty.		
1) Forward jumps (either double or single leg)		
- Double leg		2-3 x 3-5 repetitions
- Single leg (right + left)		2-3 x 3-5 + 3-5 repetitions
2) Jumps in place		
- Three alternative exercises		2-3 x 8-12 repetitions
3) Jumps over stick / sticks (either double or single leg)		
- Double leg		2-3 x 8-12 repetitions
- Single leg (right + left)		2-3 x 4-8 + 4-8 repetitions
IV Strengthening exercises		5-7 minutes
One exercise for lower legs (number 1, 2 or 3) and one exercise for core (number 4 or 5) during each training session.		
1) Double leg squat with partner on back		2-3 x 8-12 repetitions
2) Single leg split squat		2-3 x 4-8 + 4-8 repetitions
3) Nordic hamstrings		2-3 x 4-8 repetitions
4) Isometric side and front bridge (right + front + left)		2-3 x 10-30 + 10-30 + 10-30 seconds
5) Cross curl-up (right + left)		2-3 x 10-20 + 10-20 repetitions
+ Stretching exercises		(5 minutes)
Only for those players who had limits on low back function and flexibility. Stretching exercises were introduced to players during the first two training weeks. After that stretching exercises were performed on players own time.		
1) Seated hip and low back neutral zone exercise		2-3 x 20 seconds
2) Hamstring stretch (right + left)		1-2 x 20 + 20 seconds
3) Kneeling hip flexor stretch (right + left)		1-2 x 20 + 20 seconds

Examples of balance and body control exercises:



Examples of plyometric exercises:



Examples of strengthening exercises:



Figure 3. Examples of the warm-up exercises

4.2.2 Neuromuscular warm-up program and performance (V)

4.2.2.1 *Participants and randomization*

The fifth study was a cluster randomized controlled study based on the previous data set (chapter 4.2.1) with the following exception: the study population consisted of 27 female floorball teams and 222 female players who participated in baseline and follow-up performance tests. Their mean age was 24 years (range 15-42).

Stratified cluster randomization procedure to the intervention and control group teams is presented in previous chapter (4.2.1). There were 13 teams (119 players) in the intervention group and 14 teams (103 players) in the control group.

4.2.2.2 *Outcomes and data collection*

The main outcome variables were the differences of follow-up performance test means (static jump, countermovement jump, jumping over a bar, standing on a bar, and figure-of-eight running) between two study groups (control vs. intervention). The data collection procedures are presented in previous chapter (4.2.1).

4.2.2.3 *Performance tests*

Before and after the six-month intervention period, five performance tests were carried out in following order: static jump, countermovement jump, jumping over a bar, standing on a bar, and figure-of-eight running. The performance tests were largely used field tests, which were feasible and easy to perform at the training venue of each team. The descriptions of tests are presented in Table 5.

Table 5. Descriptions of the performance tests



Test 1 and 2: Static jump and Countermovement jump

Two different types of vertical jump tests were used to measure the explosive force of the extensor muscles of the lower extremities. Both jump tests were measured by using a contact mat (Newtest Powertimer, Oulu, Finland). The recorded flight time (s) was transformed to jump height (cm) by a digital timer (Asmussen and Bonde-Petersen 1974; Komi and Bosco 1978).

In the static jump the subject was asked to jump as high as possible on the contact mat, starting the jump from a static squatting position with a 90 degrees knee angle. In the countermovement jump the subject started a jump from standing upright and then making a countermovement (squat) before the vertical jump. Participants had three attempts in both jumps and the best result was used in the analyses.



Test 3: Jumping over a bar

Two-leg jumping over a bar was used to measure the sideways jumping speed (Holopainen et al. 1982). The subject was asked to jump as quickly as possible over a foamed plastic bar (length 50 cm, width 4 cm, and height 4 cm) that had been placed on the ground.

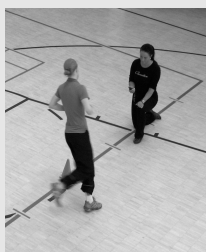
The jumping time was 15 seconds and number of properly done two-leg jumps was recorded. The stopwatch was started simultaneously with the starting signal and the ending signal finished the test. The better result from two attempts was used in the analyses.



Test 4: Standing on a bar

The standing on a bar test measured one-leg static balance (Engström et al. 1993, Rinne et al. 2001). The subject was asked to stand with her dominant leg on a narrow bar (width 2cm, height 4cm, and length 50cm) for one minute.

The stopwatch was stopped every time the subject touched the floor with the free foot and restarted when the balanced position was achieved again. The number of balance losses (and thus restarts) was the studied outcome variable. The subject was allowed to use her unsupported arms for balance. The dominant leg was tested only once.



Test 5: Figure-of-eight running

The figure-of-eight running test measured running speed and agility (Tegner et al. 1986). The subject was asked to run as fast as possible a figure-of-eight course. The course was marked with two vertical cones placed ten meters apart and the start/finish line was next to the first cone.

The stopwatch was started simultaneously with the subjects' takeoff and was stopped when the subject completed the course and crossed the finish line. The time was recorded in seconds. The better result of two attempts was recorded.

4.3 Statistical analyses

The injury incidence with 95% confidence interval (CI) was expressed either as the number of injuries per 100 000 person-years (study I), or per 1000 hours of playing and training (II-IV). In two epidemiologic studies (II-III) the incidence rate was also calculated separately for practice and games.

In the analysis of *the first study*, a Cox regression with 95% CI was conducted first to analyse the association between the background variables and cruciate ligament injury, forcing age at baseline into the model. After that, a multivariate Cox's regression model was conducted including following adjustments: occupation of fathers or other parent/guardian, family composition, urbanisation level of residence, perceived health status, chronic disease, number of stress symptoms weekly, overweight, smoking, drinking style, and timing of puberty. The adjusted hazard ratio (HR) was defined as the risk of injury between grouping variables. Independent samples t test was used when comparing the age at time of hospitalisation between sexes.

In *the second study*, means with standard deviations (SD) were used to describe continuous data, and frequency tables were used for categorical variables. In *the third study*, the incidence rate ratio (IRR) was defined as the rate of injury on the artificial floors divided by the rate of injury on the wooden floors. The unadjusted and adjusted IRRs were obtained from a Poisson model. Adjustments were done by age, BMI, training volume, floorball experience and previous injuries.

In *the fourth study*, one-way ANOVA was used to estimate the intraclass correlation coefficients (ICC) of incidence rates for injury. The unadjusted and adjusted IRRs between the two groups (intervention vs. control) were obtained from two level Poisson regression models. Cluster randomization was taken into account in the data analysis by multilevel modelling. Adjustments were done by individual (age, BMI, floorball experience, playing position, and number of orthopedic operations) and team level (league level and previous incidence of injuries). Analyses were done according to the intention-to-treat (ITT) principle. In addition to ITT, efficacy analysis was carried out to evaluate the potential benefits of high compliance and adherence to intervention training.

In *the last study*, the differences of follow-up test means between two study groups (control vs. intervention) were analyzed by multilevel regression models

taken into account the hierarchical structure of data due to cluster randomization. Adjustments were done by individual level (baseline test result, age, floorball experience, playing position, and number of orthopedic operations), and team level (league level). Analyses were performed according to the intention to treat (ITT) principle. In addition to the ITT analyses, efficacy analyses were conducted to evaluate the potential benefits of high training compliance and adherence (high indicating the players who carried out the warm-up exercises at least once a week during the 6-month follow up). In all studies, a p value <0.05 was considered statistically significant.

5. RESULTS

5.1 Epidemiologic studies

5.1.1 Cruciate ligament injuries (I)

From the total cohort of 46 472 Finns, 265 (0.6%) persons (194 males and 71 females) were treated for a cruciate ligament injury of the knee during the study period, giving an injury incidence of 60.9 (95% CI 53.6 to 68.2) per 100 000 person-years. Males had higher incidence than females, 96.6 (95% CI 83.0 to 110.2) and 30.0 (95% CI 23.2 to 37.3), respectively. The mean age at the time of injury was 22.6 years for males and 22.2 for females.

Participation in organized sports ≤ 3 times a week increased slightly but significantly the risk for cruciate ligament injury in both sexes: adjusted HR for female was 2.0 (95% CI 1.1 to 8.6) and males 2.0 (95% CI 1.4 to 2.9). In highest activity level, that is participation ≥ 4 times a week in organized sports, the injury risk increased substantially more in females than males, adjusted HR being 8.5 (95% CI 4.3 to 16.4) and 4.0 (95% CI 2.7 to 6.1), respectively.

5.1.2 Floorball injuries (II)

During the study period, a total exposure of 47 834 training and playing hours of floorball was reported. The volume of training and playing was 45 628 hours and 2206 hours, respectively. 133 out of the 374 players sustained 172 time-loss injuries, from which 89 injuries occurred in games and 83 in practice. Twenty-one players had two injuries and nine players had three injuries during the season.

The overall injury rate was 3.6 per 1000 training and playing hours. The injury occurrence was remarkably higher in games (40.3 injuries / 1000 game hours) than in practice (1.8 injuries / 1000 training hours). Injury rate per 1000 game hours in the elite league was 34.3, in first division 48.0 and in second division 47.7. Injury

rate per 1000 game hours in forward players was 51.6, in defensive players 34.8, and in goalkeepers 16.1. The average age (SD) of the injured players was 25 (5) years.

The most commonly injured sites were the knee (27%), ankle (22%), thigh (12%), and low back (8%). Lower extremity injuries seemed to be more severe than injuries at other sites (Table 6). 46% of the knee injuries were serious. During the study season, ten players sustained an ACL injury, of which eight ruptures occurred during floorball games giving an ACL incidence of 3.6 per 1000 game hours.

Table 6. The severity of the injury according to the injury site

Injury location	Injury severity		
	Minor injuries (1-7days)	Moderate injuries (8-28days)	Major injuries (>28days)
	n	n	n
Head / neck (n=9)	9	-	-
Upper extremities (n=18)	12	5	1
Trunk (n=13)	9	3	1
Lower extremities (n=132)	72	31	29
Total (n=172)	102	39	31

121 (70 %) of injuries were acute and 51 (30%) were from overuse. Most of the acute injuries involved the ankle and knee (29% and 28%), and most of the overuse injuries involved the knee (27%) and calf/shin (22%). Joint sprain was the most common injury type (Table 7). Almost all of the ankle injuries (95%) and over half (57%) of the knee injuries were acute ligament sprains or ruptures. Muscle strains and soft tissue contusions were also common injuries among these female floorball players. Nearly half (45 %) of the 121 acute injuries were non-contact-injuries. Of acute ankle and knee injuries, 59 % and 46 % occurred in non-contact circumstances, respectively. Seven of the ten ACL-ruptures were non-contact-injuries.

Table 7. Distribution of injury types (n=172) among female floorball players

Injury type	n	%
Joint and ligament injury	73	42
Muscle and tendon injury	46	27
Contusion	24	14
Undefined overuse injury	20	12
Nervous system injury	5	3
Laceration	2	1
Fracture	2	1

5.1.3 Playing surface and injury risk (III)

A total of 230 floorball games were evaluated for floorball injuries sustained while playing on artificial floors or wooden floors. The game exposure on wooden floors was 971 game hours vs. 601 hours on artificial floors. During the season, 51 players sustained 62 traumatic injuries in regular league games. Seven players had two injuries and two players had three injuries during the season. The average age (SD) of the injured players was 26 (5) years. The total injury rate was 39.4 (95 % CI 30.7 to 50.6) per 1000 game hours.

36 of all injuries occurred on artificial floors and 26 on wooden floors. The injury incidence per 1000 game hours was 59.9 (95 % CI 43.2 to 83.0) on artificial floors vs. 26.8 (95 % CI 18.2 to 39.3) on wooden floors. Adjusted incidence rate ratio (IRR) of all traumatic injuries was twofold higher (IRR=2.1; 95% CI 1.2 to 3.5, $p=0.005$) on artificial floors compared to that on wooden floors. The risk for non-contact injuries (adjusted IRR=12.5; 95% CI 2.9 to 54.9, $p=0.001$) and severe injuries (adjusted IRR=3.3; 95% CI 0.9 to 10.9, $p=0.052$) was especially high when playing on artificial floors.

5.2 Intervention studies

5.2.1 Neuromuscular warm-up program and injury risk (IV)

Concerning intervention compliance, five teams (36%) in the intervention group used the warm-up program according to the plan, six teams (43%) had some irregularities in training, and three teams (21%) interrupted the training during the follow-up. As an average, 74% of the intended training sessions could be performed as planned (Table 8).

Table 8. Compliance of intervention teams

Volume of warm-up training among intervention teams (n=14)	Mean	SD, range
Number of warm-up sessions*	31	12, 2-45
Attendance at warm-up training, % of players	69	15, 42-96
Duration of warm-up session, minutes	23.5	3.7, 19-32

* A target number of warm-up training sessions was 42 per team during the season

In the intervention group a total exposure of 32 327 scheduled training and playing hours of floorball was reported throughout the season, during which a total of 87 lower extremity injuries occurred. In the control group a total number of 102 lower extremity injuries occurred during reported exposure of 25 019 hours. Significantly fewer non-contact lower extremity injuries (adjusted IRR=0.34; 95% CI 0.20 to 0.57, $p<0.001$) occurred in the intervention group than in the control group (Table 9).

The greatest reduction was found among minor ankle ligament injuries (adjusted IRR= 0.23; 95% CI 0.07 to 0.69, $p=0.009$). There was also a consistent trend towards reductions in the moderate (2 injuries in the intervention group vs 6 injuries in the control group) and major ankle ligament injuries (1 vs 3), but due to few injury cases statistical power was too low to detect possible between-group differences.

Concerning the major knee ligament injuries, six ruptures of anterior cruciate ligament (ACL) occurred in the intervention group, of which three were non-contact injuries. In the control group there were four ACL-ruptures, of which three were non-contact injuries, respectively.

In efficacy analysis, intervention teams with high compliance and adherence for warm-up training had lower risk of injury than other intervention teams: IRR between the high compliance group and the control group was 0.19 (95% CI 0.06 to 0.64, $p=0.007$) for non-contact lower extremity injury, 0.19 (95% CI 0.05 to 0.82, $p=0.026$) for non-contact ankle ligament injury, and 0.32 (95% CI 0.04 to 2.59, $p=0.284$) for non-contact knee ligament injury.

Concerning the secondary outcome or the overall risk of lower limb injury, there was a significant difference between the groups favoring the intervention (adjusted IRR=0.70; 95% CI 0.52 to 0.93, $p=0.016$). Significantly fewer acute (non-contact and contact) lower limb injuries (adjusted IRR=0.65; 95% CI 0.47 to 0.90, $p=0.010$) were seen in the intervention group than control group. No significant differences between the intervention and control group were found for overuse lower limb injuries (adjusted IRR=0.88; 95% CI 0.48 to 1.63, $p=0.690$).

Concerning the safety of the neuromuscular warm-up program, none of the injuries occurred during structured warm-up sessions.

Table 9. Number and incidence (per 1000 practice and playing hours) of acute non-contact lower extremity injuries and incidence rate ratio for two groups

Injury type	Intervention group (n=256)		Control group (n=201)		ICC	Unadjusted IRR	p Value	Adjusted IRR *	p Value
	No	Incidence (95% CI)	No	Incidence (95% CI)					
Noncontact lower extremity	20	0.65 (0.37 to 1.13)	52	2.08 (1.58 to 2.73)	0.041	0.31 (0.17 to 0.58)	<0.001	0.34 (0.20 to 0.57)	<0.001
Ligament	15	0.48 (0.27 to 0.84)	38	1.52 (1.10 to 2.09)	0.033	0.31 (0.16 to 0.60)	<0.001	0.35 (0.19 to 0.64)	0.001
Ankle ligament	8	0.27 (0.11 to 0.64)	27	1.10 (0.71 to 1.70)	0.059	0.24 (0.09 to 0.65)	0.005	0.28 (0.12 to 0.67)	0.004
Knee ligament	7	0.22 (0.10 to 0.45)	11	0.44 (0.24 to 0.80)	0.004	0.49 (0.19 to 1.27)	0.143	0.49 (0.18 to 1.31)	0.155
Muscle strain	5	0.15 (0.06 to 0.37)	14	0.57 (0.29 to 1.12)	0.040	0.26 (0.09 to 0.72)	0.009	0.40 (0.12 to 1.32)	0.134

ICC=intra-cluster correlation coefficient for injury incidences. IRR=incidence rate ratio is obtained from two level Poisson model. Level of significance level was <0.05.

* Adjusted at individual level (age, body mass index, floorball experience, playing position, and number of orthopaedic operations) and team level (league, previous incidence of injuries). Cluster randomization was taken into account in the data analysis.

5.2.2 Neuromuscular warm-up program and performance (V)

At six months, both groups showed improvements in all performance tests (Table 10). Statistically significant between-groups differences were found in two outcome parameters; i.e. jumping over a bar (number of jumps in 15 sec), and standing on a bar (number of balance losses in 60 sec). Mean between-groups difference in the former was 2.3 jumps (95% CI 0.8 to 3.8, $p=0.003$) favoring the intervention group, and in the latter -0.4 balance losses (95% CI -0.8 to 0.0, $p=0.050$), again in the favor of the intervention group.

In efficacy analysis between high compliance players ($n=71$) and control group ($n=103$) we found similar results as in the main analysis. In jumping speed the adjusted mean difference between high compliance players vs. control group was 1.1 jumps (95% CI -0.1 to 2.3, $p=0.08$), and in static balance test the adjusted mean difference was -0.4 balance losses (95% CI -0.9 to 0.1, $p=0.10$).

Table 10. Baseline and follow-up test means and adjusted mean difference between two groups

Variables	Baseline test mean (SD)	Follow-up test mean (SD)	Mean difference estimate * (95% CI)	P value
Static jump (cm)				
Control group ($n=103$)	26.4 (4.3)	28.8 (4.2)		
Intervention group ($n=115$)	27.8 (4.7)	30.1 (5.3)	0.4 (-0.6 to 1.5)	0.43
Countermovement jump (cm)				
Control group ($n=103$)	28.1 (4.1)	30.8 (4.4)		
Intervention group ($n=115$)	29.7 (5.0)	32.0 (5.1)	0.2 (-0.8 to 1.2)	0.70
Jumping over a bar (no/15s)				
Control group ($n=102$)	43.4 (3.8)	45.7 (4.6)		
Intervention group ($n=114$)	43.6 (3.9)	47.9 (5.4)	2.3 (0.8 to 3.8)	0.003
Standing on a bar (no/60s)				
Control group ($n=102$)	1.4 (2.2)	1.3 (2.1)		
Intervention group ($n=118$)	1.6 (2.8)	1.0 (1.8)	-0.4 (-0.8 to 0.0)	0.050
Figure-of-eight running (s)				
Control group ($n=100$)	5.57 (0.30)	5.53 (0.29)		
Intervention group ($n=114$)	5.55 (0.28)	5.49 (0.28)	-0.01 (-0.06 to 0.04)	0.58

Significance level was <0.05 .

*Adjusted at individual level (baseline test result, age, floorball experience, playing position, and number of orthopedic operations) and team level (league). The cluster randomization was taken into account in the data analysis.

6. DISCUSSION

6.1 Occurrence and nature of injuries

The study series of this thesis reported the occurrence of sports injuries among floorball players in Finland. The results of *the first study* showed that risk of severe knee ligament injuries, such as ACL and PCL injuries, is high in active young women. The findings of this current population-based study are supported by previous investigations conducted among athletic populations. Such studies have shown that female athletes have up to 4-7-fold increased risk for a cruciate ligament injury compared with their male counterparts playing at similar level in same sports (Malone et al. 1993, Arendt and Dick 1995, Myklebust et al. 1998).

The highest risk for knee injuries have been found in pivoting and cutting sports like alpine skiing, basketball, football, lacrosse, soccer and team handball (Ekstrand and Gillqvist 1982, Wedderkopp et al. 1997, Natri et al. 1999, Giza et al. 2005, Hinton et al. 2005, Ramirez et al. 2006, Shankar et al. 2007, Borowski et al. 2008).

The most important finding of *the second study* of the thesis (an epidemiologic study of floorball injuries) was the upward trend of injury incidence in this sport. The injury rate in the present study was over two times higher than that reported for female players in earlier studies. Löfgren et al. (1994) calculated an injury rate of 2.5 per 1000 playing hours for male and female players. Wikström and Andersson (1997) found a rate of 8.2 per 1000 floorball game hours for female players, and Snellman and colleagues (2001) 1.0 per 1000 practice hours and 15.9 per 1000 game hours. In the present study, the injury rate was 1.8 per 1000 practice hours, and 40.3 per 1000 game hours. Thus, our study supports the concept that injury incidence has increased in female competitive floorball during recent years.

The high injury rate in female floorball equals with that found in other female team sports. Wedderkopp et al. (1997) reported 3.4 injuries per 1000 practice hours in young female handball players and 40.7 injuries per 1000 game hours. Engström et al. (1991) found the injury incidence in female soccer players to be 7 per 1000

practice hours and 24 per 1000 game hours. Conclusive comparisons between different sports are, however, difficult to make since the nature and the intensity of the sports varies and are often not well defined and reported.

In previous floorball studies, the most common injury site was the ankle and the most common injury type was ligament sprain. Wikström and Andersson (1997) reported 17 injuries in female players (n=154). The most common injury site was ankle (59% of all injuries), followed by knee (18%), and sprain was the most common injury type. In our study, the most common injury type was also sprain, but the most common injury site was the knee.

In Wikström's and Andersson's study (1997) proportion of overuse injuries was clearly lower than that of traumatic injuries. They reported that 16 (94%) of all injuries in female players were acute traumas. Snellman et al. (2001) reported that overuse injuries were the most frequent injury type in female players. In our study, 70% of injuries were traumatic and 30% were from overuse. The most traumatic injuries involved the ankle and knee (29% and 28%), and most (27%) of the overuse injuries involved the knee. In the present study, a large number of traumatic knee and ankle injuries occurred without contact between players: 59% of traumatic ankle injuries and 46% of traumatic knee injuries were non-contact injuries.

The third study of this thesis showed that the risk of traumatic injury for female floorball players is twofold higher on artificial floors than wooden floors. Moreover, the risk for severe injuries was clearly increased on artificial surface. Previous studies on surface related injuries have focused mostly on outdoor sports (Nigg and Segesser 1988, Ekstrand and Nigg 1989, Powell and Schootman 1992, Arnason et al. 1996, Orchard and Powell 2003).

However, as mentioned before, the risk of knee and ankle ligament injuries is especially high in pivoting indoor team sports such as basketball, team handball, volleyball, and floorball. Today the plastic matting surfaces are commonly used in indoor sports venues, but the influences of different surfaces on injury rate in indoor team sports have been studied scarcely.

Olsen and colleagues (2005) compared ACL injury rate between artificial and wooden floors in team handball and found over twofold higher ACL risk for female players on artificial floors (OR=2.35; 95 % CI 1.09 to 5.07). Our findings are similar: it seems that the shoe-surface interaction can be considerable extrinsic risk factors for traumatic injury in lower extremities for some players at least. However,

the occurrence of injuries in pivoting sports, particularly in knee and ankle, is not the result of any single risk factor. Instead, the injury is usually a result from the influence of many factors.

6.2 Injury prevention

The fourth study of this thesis was a cluster randomized controlled trial to evaluate the effects of a neuromuscular warm-up program on injury risk of female floorball players. The intervention program focused on improvement of players' motor skills and body control, as well as preparation of the neuromuscular system for sports specific motions. The program was designed to decline the incidence of acute non-contact lower limb injuries, which are of great concern in floorball.

Compared to the control group, the intervention group had significantly fewer injuries. A reduced injury rate was found in overall lower limb injuries as well as acute non-contact lower limb injuries. The greatest effects were observed in non-contact ankle ligament injuries.

Some previous studies have indicated that neuromuscular training probably plays a crucial role in injury prevention (Tropp et al. 1985, Hewett et al. 1999, Wedderkopp et al. 1999, Heidt et al. 2000, Söderman et al. 2000, Junge et al. 2002, Verhagen et al. 2004, Emery et al. 2005, Olsen et al. 2005, Mandelbaum et al. 2005, McGuine and Keene 2006, Soligard et al. 2008) and this intervention study supports these findings.

In the study of Hewett and co-workers (1999) showed that the multiple 6-week training program in high school sports teams decreased the rate of serious knee ligament injuries, as well as the rate of non-contact knee ligament injuries.

Study of Olsen and colleagues (2005) showed, in turn, that structured warm-up program among young handball players reduced the risk of traumatic knee and ankle injuries, and the overall risk for severe and non-contact injuries.

In the present study we found similar reductions in the risk of non-contact lower limb injuries, but when analyzing the specific injury locations, only the risk of ankle injuries reached the statistical significance. The 51% reduction in non-contact knee ligament injuries did not reach significance, but the trend was parallel with that of overall non-contact lower limb injuries.

The used neuromuscular warm-up program was a modified combination of previous intervention studies, and exercises of the program were easy to obtain and learn. As noted previously, the program was designed to reduce the incidence of acute non-contact lower limb injuries. Contact injuries, which are caused by a contact with another player (or stick or ball), are also very common in floorball, but most likely more difficult to prevent.

The warm-up program included many different exercise maneuvers with several variations, so it was not possible to determine which particular maneuvers were effective in injury prevention. However, this may not be even necessary, because floorball itself, as all other team sports, includes a wide variety of fast and dynamic movements during the game. To obtain a proper body control and correct technique in sports specific motions, it is probably wise to practice all the needed skills by varying rather largely the required tasks.

Also, it is likely that regularity of neuromuscular training is a key to injury prevention. Therefore, it is recommended to include varied neuromuscular exercises in weekly training program all the year round to maintain the preventive effect.

Five teams (36%) from the intervention group performed the warm-up training regularly through the season. Six teams (43%) had irregularities in training, and three teams (21%) interrupted the training. On the grounds of information in the warm-up diaries and players' subjective estimation of participation, it seemed that training activity was highest during the first two training periods after which it declined. However, all the intervention teams were included in analyses regardless of their intervention training activity and therefore the effect of the program might be even higher than reported. In fact, the efficacy analysis attested that the injury risk was lower among the regularly trained teams than the others.

Although severe knee ligament injuries, particularly ACL-injuries, are of concern in female floorball, in this study could not analyze the effect of the neuromuscular warm-up program on these injuries because there were too few such cases (three non-contact ACL-ruptures in both the intervention group and control group). However, it is noteworthy that none of the three ACL-ruptures in the intervention group occurred among the five teams that trained regularly through the season.

During the study it became obvious, that some players of the control group did similar type of warm-up exercises as the intervention group, because these exercises are commonly used in sports training. However, training among these controls did

not reach the level of the intervention group and if this partial contamination of the controls biased the results of the study it erred on the side of underestimating rather than overestimating the effect of the neuromuscular training on the injury risk.

In the used intervention program the main point was to concentrate in proper technique in every single exercise. To enhance motor skills and body control by using multiple exercises, coaches and athletes need a sufficient knowledge of correct technique, typical mistakes in each exercise and appropriate methods for their correction. Training with incorrect technique give weight to wrong motor function and may even increase the risk of injuries. On this account, it is outstandingly important to emphasise the importance of right technique in sports training.

This intervention study focused on adult female floorball players on three top level leagues in Finland. However, because all floorball players have a similar pattern of lower limb injuries and injury mechanisms, the used prevention program could also be effective in floorball in general including adult male players, young players and recreational players. Further studies are needed to verify the training effect in these groups.

Because the musculoskeletal changes develop during maturation, we currently recommend that regular neuromuscular training of floorball players should begin not later than the age of 12. It is also easier to learn motor skills during young age, that is to say the correction of poor motor technique may be more difficult in adulthood – at least the learning process takes substantially more time and repetitions than that in childhood.

6.3 Warm-up exercises and performance

According to *the fifth study* of this thesis, participation in a structured six-month neuromuscular warm-up program designed to enhance players' motor skills and prepare the body to upcoming floorball training turned out to improve static balance and sideways jumping speed in female floorball players. Concerning changes in vertical jumps and running speed and agility, there were no differences between intervention and control groups.

Some studies have shown that neuromuscular training is likely to enhance athletic performance (Wojtys et al. 1996a; Hewett et al. 1996; Chimera et al. 2004; Emery et al. 2005) and thereby improve lower extremity biomechanics and reduce injurious forces. The used programs differed in type, intensity, frequency, and duration, and this fact probably has a remarkable effect on measured outcomes.

Hewett et al. (1996) investigated effects of six weeks intensive and progressive jump and weight training program on landing mechanics and lower limb strength in female athletes. The training session lasted about two hours and it was repeated three times a week. After the training period, landing forces from jump decreased and knee control increased among the trained female athletes. In addition, vertical jump height and hamstring-to-quadriceps muscle torque ratios increased in the trained group.

Chimera and colleagues (2004) evaluated the effects of jump training on muscle-activation strategies and performance of lower extremity during six weeks intensive plyometric training period. Experimental group of female athletes performed jump exercises two times per week and one training session took about 20-30 minutes. They found significant increase in preparatory adductor muscle firing, adductor-to-abductor muscle co-activation and quadriceps-to-hamstring muscle co-activation in the intervention group. Findings supported the importance of hip-musculature activation strategies for lower extremity control, which interact in biomechanics and reduce harmful forces.

Emery et al. (2005) studied effectiveness of home-based balance-training program among male high-school students. The training program included two- and one-legged balance exercises with wobble board and trunk stabilization exercises. Students were advised to use balance-training program daily for six weeks, one training session lasted about 20 minutes. Balance test battery included static balance test (one-legged standing on the floor) and dynamic balance test (one-legged standing on the balance pad). Improvements in static and dynamic balance during the follow-up were significantly greater in the intervention group than control group.

Our neuromuscular training program included running technique, balance, jumping and strengthening exercises with several variations, and it was designed to replace the traditional warm-up before structured floorball training. The intensity in each exercise was low-to-moderate. Therefore it was obvious that this training

program might not improve all measured outcomes. The program did not, for example, include exercises which aim to improve maximal vertical jump height. Systematic strength and power training, such as the one in study of Hewett et al. (1996), are needed to improve muscle power. On the other hand, it was logical that warm-up exercises enhanced static balance and sideways jumping performance because every warm-up session included different variations of one-legged standing and rebound jump series.

In efficacy analysis we did not find greater improvements among the high compliance players. However, it is noteworthy that the high compliance players (n=71) had slightly better baseline test results than others in the intervention group. This may intend that those hardworking players may have had higher training volume, better condition and neuromuscular performance in general. At the same time, those players who had lower baseline results could improve their neuromuscular performance by smaller amount of training. This may signify that improvements in jumping speed and static balance are rather easy to attain at the initial stage of training or among novice players, even with irregular training.

Though these warm-up exercises did not improve all of the measured outcomes, we feel that they should be practiced before sports-specific training since they have been shown to be effective in injury prevention. The main point in comprehensive warm-up exercises is to activate athletes' proprioception and motor control, and thereby prepare the neuromuscular system for upcoming sports training. If upcoming sport training or playing includes for example one-legged movements, upper body rotations and running in different directions, it would be reasonable to practice those maneuvers during the warm-up session.

Systematic warm-up exercises are also excellent way to learn and maintain motor skills for each sport. On this account, in the present intervention the main point in each exercise was to focus on proper technique, such as good playing posture, neutral zone of lumbar spine, trunk stability, and position and function of the hip, knee and foot (especially "knee-over-toe" position) during the sports-specific maneuvers. Besides, the neuromuscular warm-up exercises were safe to perform and can be thus recommended to be included in the weekly training of this sport.

6.4 Methodological considerations

The first study was a population-based prospective cohort study involving a large and nationwide sample of adolescents over a remarkably long follow-up period (a total of 435 840 person-years). The data used in the study was combined data based on three data sets from AHLS, NHDR and CDS. Comparability of the AHLS data has been controlled by means of maintaining the sampling, research methods, questions and timing as similar as possible over the years. Also coverage and accuracy of the NHDR and CDS data have been shown to be very good (Salmela and Koistinen 1987, Keskimäki and Aro 1991).

There were also some limitations in this first study. First, although the overall response rates of the adolescents were very good, they declined somewhat over the years. However, the analysis of non-respondents showed that non-respondents had similar risk for cruciate ligament injury to that of the respondents, allowing us to conclude that non-response did not have a significant effect on results.

Second, it is possible that before 1994 a few individuals with a cruciate ligament injury were treated on outpatient basis or at private clinics and thus not registered in the NHDR. Until 1993, the NHDR covered all hospitals in Finland and all inpatient stays were registered. From 1994, the data was collected more accurately, and the NHDR (re-named as the Care Register) was widened to cover also day surgery cases (Stakes 2003). However, during the study years, outpatient care was quite rare among patients with cruciate ligament injury.

The second study was a prospective cohort study in Finnish female floorball players with six-month follow-up. Exposures were based on individual training diaries, which gave an actual training and playing hours of each player. The contact person of each team held injury questionnaires and diaries during the season. When an injury occurred, the contact person gave an injury questionnaire to the injured player, and helped her to complete it if necessary. The contact person sent the completed injury questionnaire to the study physician, who then contacted and interviewed the injured players and checked the accuracy of individual injury information. In addition, the study researcher contacted all the team coaches and contact persons regularly to assure the coverage of the injuries.

However, there were also some limitations in the second study. First, although the injury information was collected precisely, all minor injuries may not have been

reported. Second, the sample size (n=374) can also be seen as a limitation of the study as it prevents subanalysis of the data, for e.g., for ACL injuries.

The third study was a prospective cohort study based on the previous mentioned data set, and the strengths of the injury and exposure data collection were described above. In this study we compared injury incidences between two different floor types, which clearly differ from each other in the covering materials and friction properties.

However, it must be taken into consideration that all the wooden floors and artificial floors are not similar. Freshly varnished and clean wooden floors can have a higher friction than their dusty counterparts. Also, friction between different artificial floors varies. In general, however, the artificial floors clearly have higher friction than wooden floors (Olsen et al. 2005, Kyyhkynen 2007). A second limitation of the study was that the exact information of players' shoes was lacking. Ideally, each shoe model should be tested on different surfaces for exact information on friction.

The fourth study was a cluster randomized controlled study in Finnish female floorball players with six-month follow-up. The coverage of the study was high: 86% of all eligible players from 28 floorball teams could be recruited. In addition, the intervention and control groups were similar in baseline characteristics, drop out rate, and floorball exposure during the follow-up.

Compliance in collecting the exposure and injury data was also very good. Exposure data were collected on a group basis, meaning that the coach of each team reported the number of games and structured practices (duration of each practice session and number of attended players). Injury data was collected in the same way as in the second study.

The RCT study had also some limitations. Firstly, absence of a possibility to full double blinding in this type of study limits the strength of the conclusions. Randomization phase, data collection and data analysis were blinded, but for obvious reason neither the coaches nor the players' could be masked. Second, the sample size was sufficient for injury analyses concerning all non-contact lower limb injuries but too small for analysing the anatomical subgroups in detail.

The fifth study was a cluster randomized controlled study based on the previously described population of floorball players. As in the previously described RCT, a study design of this trial was robust and reduced the potential biases and thus

increased the reliability of the results. Second, the intervention and control groups were similar in baseline characteristics, drop out rate, and training and playing exposure during the six-month follow-up. The neuromuscular warm-up activity in the intervention group was good.

Though the initial rate to participate the tests was quite high, the general participation rate to the follow-up tests could have been better. The drop out rate was 36% and this may have influenced the results, although the proportion of drop outs was similar in both groups. In fact, it was a great challenge to arrange suitable testing times for all players in the amateur sports.

It was also obvious that some players in the control group used similar neuromuscular exercises as those in the intervention groups. However, it is likely that the training volume and quality among these controls did not reach the level of the intervention group.

6.5 Implications for further studies

The main findings in this study indicate that non-contact injuries of lower extremities, which are common in female floorball, are largely preventable. However, similar research is needed also with larger sample size in order that we could assess the effects on some anatomical subgroups, such as severe knee injuries and overuse injuries.

Accordingly, more exact information on sports-specific risk factors, including more accurate measurements of friction characteristics, malalignments, and injury mechanisms, are needed for designing effective prevention strategies. In addition, the feasibility of the neuromuscular warm-up program should be explored in other sports and target groups, such as male players, young players and recreational players.

This study also showed that the neuromuscular warm-up program enhanced some of the measured performance properties of the players. Developments in players' jumping speed and static balance may signify about improvements on leg control and muscle activity. The selected performance tests were largely used field tests, which were feasible and easy to perform.

The challenge for future research is to explore the more precise effects of neuromuscular training to players' body control, such as hip, knee and foot positions, as well as muscle activation patterns, side-to-side differences and motor skills. These tests should measure sports-specific maneuvers, such as running, stopping, jumping and change of direction.

7. CONCLUSIONS

Referring to the original aims of the study in chapter 3, the conclusions can be summarized as follows:

- 1 The risk for cruciate ligament injury of the knee is clearly raised among adolescents engaged in organized sports, and the risk is especially high in young athletic women. (I)
- 2 The injury rate is high in female floorball, especially during games. Female floorball players have a great risk for ligament injuries of the knee and ankle, and considerable part of these injuries occur in non-contact circumstances. About half of the knee injuries are serious causing time-loss of over 28 days. (II)
- 3 The risk of acute injury is twofold higher when playing on artificial than wooden floors. Moreover, the rate of non-contact and severe injuries was over 12 and 3 times higher on artificial floors. (III)
- 4 The neuromuscular warm-up program is effective in preventing acute non contact injuries of lower extremity in female floorball players. Neuromuscular exercises should be included in the weekly training of floorball. (IV)
- 5 The neuromuscular warm-up program is effective in enhancing floorball players' sideways jumping speed and static balance. (V)
- 6 The neuromuscular warm-up exercises are safe to perform. (IV, V)

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ORIGINAL PUBLICATIONS

The risk for a cruciate ligament injury of the knee in adolescents and young adults: a population-based cohort study of 46 500 people with a 9 year follow-up

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ABSTRACT

Objectives: The knee joint is the most common site for injury among younger people, the injury often resulting in expensive (surgical) treatment, long-term rehabilitation and permanent functional impairment and disability.

Methods: We investigated the incidence and risk factors for a major knee-ligament injury in an adolescent Finnish population. A population-based cohort of 46 472 adolescents was followed for an average of 9 years. All patients hospitalised with the diagnosis of anterior or posterior cruciate ligament injury (ACL or PCL injury) were included in the analysis.

Results: 265 (0.6%) people (194 male and 71 female subjects) from the total cohort of 46 472 were treated for a cruciate ligament injury of the knee during the follow-up period, giving an injury incidence of 60.9 (95% CI 53.6 to 68.2) per 100 000 person-years. When the socioeconomic, health and lifestyle background variables were taken into account, the adjusted hazard ratio for a cruciate ligament injury of the knee was 8.5 (95% CI 4.3 to 16.4) for female and 4.0 (95% CI 2.7 to 6.1) for male subjects who participated in organised sports ≥ 4 times/week.

Conclusions: The general risk for a cruciate ligament injury of the knee is relatively low among adolescents and young adults, but participation in organised sports increases the risk significantly. The risk is especially high in active young women. Preventive measures should be adopted to decrease the short-term and long-term burden of these severe injuries.

Current public health recommendations strongly recommend regular physical activity to improve cardiovascular health and reduce the risk of chronic diseases.¹ However, with increasing physical activity, the risk of musculoskeletal injury also increases. Owing to the very large and increasing number of injuries induced by physical activity among adolescents and young adults, such injuries are currently considered a marked public-health burden.^{2 3}

Because of its anatomical location, the knee joint is subjected to tremendous forces during exercise and physical activity, thus, it is not surprising that this joint is the most common site for a sport-related injury, usually accounting for 15–30% of all such injuries.^{4 5} In addition, the knee joint is a common site for severe injuries, such as ruptures of the anterior or posterior cruciate ligament (ACL or PCL). These injuries frequently need surgical treatment and long-term rehabilitation and may result in functional impairment and permanent

disability.^{2 4 6 7} They are also very costly.⁸ In the USA, which has a rate of about 250 000 cruciate ligament injuries per year, a conservative estimate of surgical and rehabilitative costs of one cruciate ligament injury is about US\$17 000.^{6 9} Moreover, the long-term costs of a cruciate ligament injury may be significantly greater, as the risk of radiographically diagnosed knee osteoarthritis later in life is increased by up to 105 times.¹⁰

Despite these results, the frequency of and risk factors for knee injuries in adolescents are not well established. Therefore, the aim of this prospective cohort study was to investigate the incidence of a major knee ligament injury in a general adolescent population and to compare sports with socioeconomic, health and other lifestyle background variables to obtain insight into how strong a risk factor is sports participation for these injuries.

METHODS

Approval for the study was obtained from the institutional review board of the National Research and Development Center for Welfare and Health (6267/54/2002) for the use of the National Hospital Discharge Register and, from Statistics Finland (TK-53-1526-04) for the use of the Official Cause-of-Death Statistics.

Baseline cohort

Combining survey data with data from national injury registers we obtained longitudinal information on cruciate ligament injuries of the knee and associated risk factors. The Adolescent Health and Lifestyle Survey is a nationwide monitoring system of adolescent health and health-related lifestyle in Finland, conducted as a postal survey on alternate years since 1977.^{11 12} Two reminders are sent to non-respondents after 3 and 7 weeks. The materials with respect to sampling, research methods, questions and time of inquiry have been maintained as similarly as possible for each year.

Our sample of adolescents aged 14, 16 and 18 years was drawn from the National Population Register Center through the selection of all Finns born on certain days in June, July or August. The mean ages of the respondents were 14.6, 16.6 and 18.6 years. Baseline data for the purpose of the present study was collected from 1987 to 1997. The baseline population consisted of 59 403 people, of whom 46 531 responded to the Adolescent Health and Lifestyle Survey, the response rate being 78% (table 1).

Table 1 Age, number and response rates of the study subjects

Baseline year	Age at follow-up in 2001 (years)	Age at baseline (years)	Participants (n)		Response rate (%)	
			Male	Female	Male	Female
1987	29	14	1674	1789	81	89
	31	16	1383	1479	80	89
	33	18	1012	1274	74	89
1989	27	14	360	431	75	90
	29	16	362	380	70	82
	31	18	326	407	63	80
1991	25	14	1629	1837	74	87
	27	16	1562	1912	71	87
	29	18	1286	1626	61	82
1993	23	14	1861	2008	75	88
	25	16	1655	1943	71	87
	27	18	1460	1791	67	84
1995	21	14	1177	1301	75	85
	23	16	1232	1469	72	88
	25	18	1071	1313	67	86
1997	19	14	1168	1346	69	84
	21	16	1126	1379	68	87
	23	18	1088	1414	60	83
Total	—	—	21432	25099	71	86

Cruciate ligament injury data

The follow-up started after the survey ended on 30 April of each data-collection year. The end-points in the study were the date of the first cruciate ligament injury hospitalisation (obtained from the National Hospital Discharge Register), the date of death (obtained from the Official Cause-of-Death Statistics), or the end of the study on 31 December 2001. The respondents were followed up for an average of 9.3 years, the total follow-up time being 435 840 person-years.

The hospitalisation data were obtained from the statutory, computer-based National Hospital Discharge Register of Finland, which contains data on the diagnosis, length of stay, location and cause of injury, possible surgery, age and place of residence of all patients in this country. The information is systematically collected from all hospital categories (public, private, military and other). The main outcome variable was patients hospitalised with the main or secondary diagnosis of ACL or PCL injury.

The diagnoses in the National Hospital Discharge Register were coded using the 9th (1987–1995) and 10th (1996–2001) revisions of the International Classification of Diseases (ICD). Cruciate ligament hospitalisation was defined by the ICD-9 codes 8442A and 8442B and by the ICD-10 code S83.5. In the analyses, ACL and PCL injuries were combined because ICD-10 uses code S83.5 for both of these injuries. During the years 1987–1995, 8% of the injuries involved the PCL. A recent validation study showed that the coverage (92%) and accuracy (89%) of diagnosis of cruciate ligament injury of the knee in the Finnish National Hospital Discharge register are very good for epidemiological purposes.¹³

People who had been hospitalised with cruciate ligament injury before entering to the sample (ie before the response date), were excluded from analysis ($n = 73$), whereas people who died during the follow-up ($n = 257$) were followed up until the time of death. As noted above, the data concerning deaths were obtained from the Finnish Official Cause-of-Death Statistics, which is also a statutory, computer-based register covering the entire population.¹⁴

Physical activity variables as risk factors for the injury

Frequency of participation in sports clubs and other physical activity in adolescence was analysed with following alternatives: never, ≤ 3 times/week and ≥ 4 –5 times/week. Other physical activity was measured by combining three variables describing physical activity; (1) organised by school or workplace, (2b) organised by associations other than sports clubs and (3) participated in alone or with friends or family members.

Other background variables as risk factors for the injury

Altogether, 11 additional categorical variables from the Adolescent Health and Lifestyle Survey were used in the analysis. These were obtained as adolescents' self-reports, with the exception of age, sex and urbanisation level of residence, the latter derived from the sample information (Population Register Center). Respondent's socioeconomic background was measured by the education of the father or other parent/guardian, family composition and urbanisation level of residence. Adolescents' health was assessed on the basis of their self-reports on perceived health status, chronic disease or disability restricting daily activities and by counting a summary index of eight stress symptoms (stomach aches, tension, irritability, sleep difficulties, headache, trembling of hands, feeling tired or weak, feeling dizzy) perceived weekly. Body mass index (BMI) was calculated by dividing weight (kg) by the height in meters squared, (m) and the cut-off points for overweight were set according to Cole and colleagues.¹⁵

The timing of puberty was assessed by questions about the respondent's age at the time of the first ejaculation (boys) and first menstruation (girls) and classified into three categories: early (≤ 12 years in boys and ≤ 11 years in girls), average (13 or 14 years in boys and 12 or 13 years in girls) and late (≥ 15 years in boys and ≥ 14 years in girls). Adolescents' health-compromising behaviours were described by daily use of tobacco and the drinking style (abstinence, occasional drinking, recurrent drinking, recurring drunkenness).

Statistical methods

The statistical analyses were carried out in two stages, separately for boys and girls. There were two exclusion criteria: non-respondents to the questionnaire and respondents who had not answered the questions investigated in this study.

In the analysis, we first conducted Cox regression with 95% CI to analyse the association between the background variables and cruciate ligament injury hospitalisation, forcing age at baseline into the model. Thereafter, a multivariate Cox's regression model was conducted including adjustment for occupation of father or other parent/guardian, family composition, urbanisation level of residence, perceived health status, chronic disease, number of stress symptoms weekly, overweight, smoking, drinking style and timing of puberty. Independent samples *t* test was used when comparing the age at time of hospitalisation between sexes.

Finally, we compared respondents and non-respondents across the follow-up years to determine if any specific differences might exist between the groups relevant to this study. The non-respondents to the baseline surveys had 1.1 times (95% CI 0.8 to 1.4) the risk of ACL/PCL hospitalisation than the respondents, thus indicating random or nonbiased selection of the study respondents.

Original article

Table 2 Adolescent socioeconomic, health and lifestyle variables* as predictors for a cruciate ligament injury hospitalisation during the follow-up

Background variable	Hazard ratio (95% CI) for cruciate ligament injury	
	Boys	Girls
Urbanisation level of residence		
Capital area (Helsinki and adjoining towns)	1	1
Large town (population >100 000)	1.0 (0.5 to 2.0)	0.7 (0.2 to 1.8)
Small town	1.1 (0.7 to 1.9)	0.7 (0.4 to 1.4)
Village	0.9 (0.5 to 1.5)	0.5 (0.2 to 1.0)
Sparsely populated rural municipality	0.7 (0.4 to 1.3)	0.5 (0.2 to 1.3)
Education of father or other parent/guardian		
High	1	1
Middle	1.0 (0.6 to 1.7)	1.4 (0.7 to 2.7)
Low	0.9 (0.6 to 1.4)	0.7 (0.4 to 1.3)
Family composition		
Nuclear (both parents were adolescent's own)	1	1
Non-nuclear	1.3 (0.9 to 1.8)	0.9 (0.5 to 1.5)
Perceived health status		
Excellent	1	1
Good	0.6 (0.5 to 0.8)	0.6 (0.4 to 1.0)
Poor	0.4 (0.3 to 0.7)	0.5 (0.2 to 0.9)
Chronic disease or disability		
No	1	1
Yes	1.0 (0.6 to 1.7)	1.4 (0.7 to 2.7)
Number of stress symptoms weekly		
0	1	1
1	1.3 (1.0 to 1.9)	1.0 (0.6 to 1.8)
2	0.9 (0.5 to 1.4)	0.6 (0.3 to 1.2)
3+	0.8 (0.5 to 1.3)	1.0 (0.6 to 1.8)
Overweight		
No	1	1
Yes	1.1 (0.8 to 1.7)	1.5 (0.8 to 3.1)
Smoking		
Not daily	1	1
Daily	0.9 (0.7 to 1.3)	0.6 (0.3 to 1.2)
Drinking style		
Abstinence	1	1
Occasional drinking	0.7 (0.5 to 1.0)	1.5 (0.7 to 3.4)
Recurrent drinking	0.8 (0.6 to 1.1)	1.7 (0.8 to 3.7)
Recurring drunkenness	0.6 (0.4 to 1.0)	1.5 (0.6 to 3.7)
Frequency of participation in sports clubs		
Never	1	1
2–3 times a week or less	2.1 (1.5 to 3.0)	2.1 (1.2 to 3.6)
4–5 times a week or more	4.1 (3.2 to 6.4)	11.5 (6.7 to 19.8)
Frequency of other physical activity		
Never	1	1
2–3 times a week or less	1.8 (0.7 to 4.9)	0.9 (0.2 to 3.5)
4–5 times a week or more	2.2 (0.8 to 6.0)	1.5 (0.4 to 6.3)
Timing of puberty		
Early	1	1
Normal	1.1 (0.8 to 1.5)	1.3 (0.7 to 2.7)
Late	0.9 (0.6 to 1.3)	1.4 (0.6 to 3.2)

*Estimated by separate Cox regression models.

The hazard ratios are age-adjusted.

RESULTS

Altogether 265 (0.6%) people (194 boys and 71 girls) from the total cohort of 46 472 people were hospitalised for a cruciate ligament injury of the knee during the follow-up, giving an injury incidence of 60.9 (95% CI 53.6 to 68.2) per 100 000 person-years. The injury incidence was 96.6 (95% CI 83.0 to 110.2) in male subjects and 30.0 (95% CI 23.2 to 37.3) in female

subjects. The mean age at the time of the injury was 22.6 years for male subjects and 22.2 years for female subjects ($p = 0.5$).

Of the measured socioeconomic, health and lifestyle background variables, participation in organised sports showed the strongest association with hospitalisation for cruciate ligament injury (tables 2 and 3). Participation in organised sports ≤ 3 times/week involved a slightly but statistically significantly increased risk for cruciate ligament injury (adjusted hazard ratio (HR) 2.0 (95% CI 1.1 to 8.6) for female subjects and 2.0 (95% CI 1.4 to 2.9) for male subjects). Higher-activity participation was associated with higher risk for the injury: in female subjects, the adjusted HR for a cruciate ligament injury was 8.5 (95% CI 4.3 to 16.4) and, in male subjects, the corresponding figure was 4.0 (95% CI 2.7 to 6.1) (table 3).

DISCUSSION

This population-based prospective cohort study showed that the general risk for a cruciate ligament injury of the knee is relatively low among adolescents and young adults, but participation to organised sports increases the risk significantly. The risk is especially high in active young women.

The current study had a number of strengths. First, it involved a large, prospective, nationwide sample of adolescents over a remarkably long follow-up period (a total of 435 840 person-years). Second, medical treatment is equally available to everyone in Finland, ensuring the overall completeness of the used hospitalisation database. In addition, the coverage and accuracy of the National Hospital Discharge Register have been shown to be very good.^{13 16 17}

There were also some limitations to the study. First, although the overall response rates of the adolescents were very good, they declined somewhat over the years. However, the analysis of non-respondents showed that non-respondents had a similar risk for cruciate ligament injury to that of the respondents, allowing us to conclude that non-response did not have a significant effect on the results. Second, it is possible that a few individuals with a cruciate ligament injury were treated on an outpatient basis and thus not registered in the national hospital discharge register. However, during the study years, outpatient care was rare among patients with a cruciate ligament injury.

The findings of the current population-based study are supported by previous investigations conducted among athletic populations. Such studies have shown that female athletes have up to a 4–7-fold increased risk for a cruciate ligament injury compared with their male counterparts playing at similar levels in the same sports.^{18–20} The highest risks for knee injuries have been found in pivoting sports such as downhill skiing, basketball, football, team handball, floorball, soccer and ice-hockey.^{2–4 20}

The reasons for the increased risk of knee ligament injury in female athletes are multifactorial, the most common explanations being anatomical, hormonal and training related.^{21 22} In our very recent prospective study among top-level female athletes, up to 70% of the cruciate ligament injuries were caused without contact with other players, thus indicating that intrinsic, person-related factors are of importance.²³ In that study, the incidence of cruciate ligament injury of the knee was 5348 per 100 000 person-years (5.3% per year). In the current study, the cruciate ligament injury incidence in our general female population was clearly lower, being only 30 (95% CI 23 to 37) per 100 000 person-years.

A major problem after a cruciate ligament injury is that, regardless of treatment, athletes with the injury retire from the active participation at a higher rate than athletes without this injury.^{24 25} This is usually due to residual knee instability,

Table 3 Anterior cruciate ligament injury by sex and physical activity category

	ACL injury, n (%)				Hazard ratio for injury			
	Present		Absent (%)		Unadjusted		Adjusted*	
	Male	Female	Male	Female	Male	Female	Male	Female
Frequency of participation in sports clubs								
≥4–5 times/week	60 (2.0)	22 (1.6)	2890 (98.0)	1381 (98.4)	4.5 (3.2 to 6.5)	11.7 (6.6 to 20.7)	4.0 (2.7 to 6.1)	8.5 (4.3 to 16.4)
≤2 to 3 times/week	74 (1.0)	23 (0.3)	7048 (99.0)	7287 (99.7)	2.1 (1.5 to 3.0)	2.1 (1.2 to 3.7)	2.0 (1.4 to 2.9)	2.0 (1.1 to 8.6)
Never	56 (0.5)	26 (0.2)	10672 (99.5)	15860 (99.8)	1	1	1	1
Frequency of other physical exercise								
≥4 to 5 times/week	51 (1.0)	22 (0.4)	5140 (99.0)	5168 (99.6)	2.0 (0.7 to 5.4)	N/A	1.9 (0.6 to 5.7)	N/A
≤2 to 3 times/week	137 (0.9)	48 (0.3)	14,752 (99.1)	18845 (99.7)	1.9 (0.6 to 4.6)		1.8 (0.6 to 5.7)	
Never	4 (0.4)	0 (0)	928 (99.6)	756 (100)	1		1	

N/A, not applicable.

*Adjusted for father's or other guardian's occupation, family composition, urbanisation level of residence, perceived health status, chronic disease, number of stress symptoms weekly, overweight, smoking, drinking style and timing of puberty.

reduced range of motion, stiffness and pain, alone or in combination. In addition, unwillingness to take risks for further injury or distrust in the body's capacity contribute to the decision to retire.²⁶

Our findings emphasise that strong and immediate action should be taken to prevent sport-related knee injuries. In fact, it should be regarded as one of the most important factors in training and coaching.^{27–28} Caraffa *et al* conducted a prospective controlled, non-randomised study to assess the effect of proprioceptive training (including wobble-board exercises) in preventing ACL injuries among soccer players.²⁹ They showed a significantly lower incidence of ACL injury in the training group compared with controls (0.15 vs 1.15 injuries per team/season, respectively). However, although balance-board training has been shown to be effective in preventing ankle injuries, there is not yet enough evidence that this type of training alone can reduce the risk for knee injuries.^{28–30–31}

Multidimensional training trials have, in general, indicated that sport-related injuries could be prevented by using these prophylactic training regimens.²⁸ For example, Hewett *et al*

found that a specific three-phase plyometric neuromuscular training programme for female athletes significantly reduced the incidence of knee injuries in the intervention group.⁶ It is likely that the preventive effect of this and other training programmes was the sum effect of several individual methods. However, because of the complexity of designs of these studies, it is currently impossible to clarify the effectiveness of individual components of the intervention programme used. In addition, the effects of detraining on injury risk are largely unknown, although it is likely that a year-round and regular neuromuscular training is needed to maintain the injury-preventive effect.

CONCLUSION

Our prospective, population-based epidemiologic study showed that among adolescents engaged in organised sports the risk for cruciate ligament injury of the knee is clearly raised, and is especially high in athletic young females. Preventive measures should be adopted to decrease the short-term and long-term burden of this severe injury.

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What is already known on this topic

- The knee joint is the most common site for injury among younger people.
- The injury often results in surgical treatment and long-term rehabilitation.
- A cruciate ligament injury of the knee is associated with an increase in risk of up to 105 times for radiographically diagnosed knee osteoarthritis later in life.

What this study adds

- Follow-up of a Finnish adolescent population comprising 435 840 person-years showed that the general risk for a cruciate ligament injury of the knee is relatively low among adolescents and young adults.
- Participation in organised sports increases the risk of a cruciate ligament injury of the knee significantly, and the risk is especially high in active young women.
- More effective preventive measures should be adopted among young athletes to avoid severe knee injuries.

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Artificial playing surface increases the injury risk in pivoting indoor sports: a prospective one-season follow-up study in Finnish female floorball

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ABSTRACT

Objectives: To compare the injury risk in pivoting indoor sports between two different surfaces: artificial floors and wooden floors.

Methods: Female players (n = 331) from 26 top-level Finnish floorball teams were followed for one competitive season (6 months). All traumatic game related time-loss injuries were recorded. Injury incidences were calculated as the number of injuries per 1000 game hours for both surfaces. Incidence rate ratios (IRRs) were obtained from Poisson regression models.

Results: Over the competitive season, 62 traumatic injuries occurred during the games. The injury incidence per 1000 playing hours was 59.9 (95% CI 43.2 to 83.0) on artificial floors and 26.8 (95% CI 18.2 to 39.3) on wooden floors, the adjusted IRR being twofold higher (IRR = 2.1; 95% CI 1.2 to 3.5, p = 0.005) on artificial floors than wooden floors. The risk for non-contact injuries (adjusted IRR = 12.5; 95% CI 2.9 to 54.9, p = 0.001) and severe injuries (adjusted IRR = 3.3; 95% CI 0.9 to 10.9, p = 0.052) was especially high when playing on artificial floors.

Conclusions: The study attested that the risk of traumatic injury in pivoting indoor sports is higher when playing on artificial floors than wooden floors. The higher shoe-surface friction on the former surface is likely to explain the higher injury risk.

Floorball is a fast growing indoor team sports that has become very popular in Europe during the last decade. The International Floorball Federation consists of 38 member associations with more than 3700 clubs and more than 250 000 licensed players. The largest member associations are in Sweden, Finland, Switzerland, Czech Republic and Norway.¹ Floorball can be described as hockey played indoors on a court (20×40 m) surrounded by a low board. Each of the opposing teams consists usually of 15–20 players, and five field players and a goalkeeper are on the court at the same time. The players use graphite compound sticks and a light plastic ball. Playing time is 3×20 min. The playing surface can consist of wood (parquet) or artificial materials (plastic covering).

There seem to be two main factors involved in surface-related injuries: hardness of a surface and friction between the sports shoe and surface. Hardness of surface has been associated with overuse injuries in soccer.² High friction has been suggested to be an important risk factor of traumatic injuries. Powell and Schootman³ compared knee injury risk between artificial turf and natural grass in American football. They found

that higher friction between players' shoe and surface on artificial turf slightly increased the risk of knee ligament injuries. Also, higher friction may lead to increased running speed. Field hockey and football players had higher running speeds on artificial surface compared with natural grass.^{4 5} Higher playing speeds may increase the risk of collision injuries. On the other hand, if the friction is too low then this may cause slipping-related injuries.

A possible connection between surface and injury risk in indoor team sports has rarely been studied. Olsen and colleagues⁶ compared the rate of injury of the anterior cruciate ligament (ACL) of the knee between artificial and wooden floors in team handball and found higher ACL risk for female players on artificial floors. The influence of floor type on injury risk has not been investigated in floorball.

Although growing in popularity, floorball is a sports known to produce lots of injuries, the knee and ankle being the most commonly injured sites.^{7–10} Use of artificial surfaces has increased in floorball venues in recent years, and this may partly explain the growing injury rate in this sports.^{9 10} The purpose of this prospective study was to compare the incidence of traumatic floorball injuries between two surfaces: artificial floors and wooden floors.

METHODS

Participants

Female players (n = 331) were recruited from 26 Finnish top level floorball teams (Elite league and First division). The study arrangements in each participating team confirmed that the coach and contact person of the team agreed to co-operate with the research group. A contact person and coach told the players about the upcoming investigation before the follow-up period started. Final participation was based on the informed consent of each player.

All players who were injury- and symptom-free at the onset of the study completed a questionnaire about background information including anthropometrics, previous injuries, floorball experience and training participation. Table 1 shows the baseline characteristics of players.

Exposure registration

Each player wrote-up her active floorball game time hours in her personal exercise diary. Exposure time was counted for both floor types: active game hours on artificial floors and on wooden floors.

Table 1 Characteristics of players (n = 331)

Characteristic	Mean	SD
Age (years)	25.5	5
Height (cm)	166	5
Weight (kg)	61.5	6.5
Floorball experience (years)	7	3
Training per week (h)	5	2

Information on the floor type (parquet or artificial floor) at each game was given by the Finnish Floorball Federation. All teams played on both playing surfaces during the season.

Injury registration

All injuries were registered with a structured questionnaire. Table 2 gives details about the questionnaire. After each follow-up month, the contact person collected the questionnaires and diaries, and mailed them to the research group. The study physician, in turn, contacted the injured player after every new injury and checked the accuracy and consistency of the completed questionnaire. Additionally, once per month the researchers contacted the teams to check the completeness and coverage of the registration concerning new injuries.

Injury definitions

An injury was defined as any traumatic injury occurring during a regular Elite league or First division floorball game making the player unable to participate a game or practice session during the following 24 h. Injuries occurring in practices or in other games (eg, European cup, National cup, junior games or tournaments) were excluded. The severity of injury was defined according to Ekstrand and colleagues: minor injury, an injury causing absence from practice of 1–7 days; moderate injury, an injury causing absence from practice of 8–28 days; major injury, an injury causing absence from practice of more than 28 days.²

Drop-outs during the study

Seventeen players (5%) dropped out during the study period: nine stopped playing floorball for an unknown reason and eight because of severe injury. In addition, two new players were included in the study in the middle of the season, immediately after they started to play floorball in the participating teams. Data from these players who dropped out or joined in during the study were included in the analyses for the time they participated.

Table 2 Injury data collected in the standardised questionnaire

1.	Age
2.	Team name
3.	Division
4.	Date of injury
5.	Name of the venue where the injury occurred
6.	Type of game
7.	Field position when the injury occurred
8.	Type of the floor when the injury occurred (parquet, artificial)
9.	Injury location
10.	Injury type
11.	Cause of the injury (how the injury occurred)
12.	Treatment for the injury
13.	Time-loss from practices/games (how many days)
14.	Diagnosis of the injury (made by a physician)

Statistical analysis

Analyses were performed with STATA, version 8.2 (2004; Stata Corporation, Lakeway Drive, TX, USA). The injury incidence was expressed as the number of injuries per 1000 h of playing and presented with 95% CIs. The incidence rate ratio (IRR) was defined as the rate of injury on the artificial floors versus the rate of injury on the wooden floors. The unadjusted and adjusted IRRs were obtained from a Poisson model. A p value <0.05 was considered significant. Age-adjustment was used in statistical analyses on the grounds of somewhat different exposure times on the two floor types in different age groups. Other adjustments were done by body mass index, training volume, floorball experience and previous injuries.

RESULTS

Exposure and injuries during the season

A total of 230 floorball games were evaluated for floorball injuries sustained while playing on artificial floors or wooden floors. The game exposure on wooden floors was 971 game hours versus 601 game hours on artificial floors. During the season, 51 players sustained 62 traumatic injuries in regular league games. Seven players had two injuries and two players had three injuries during the season. The average age of the injured players was 26 (SD 5) years. The total injury rate was 39.4 (95% CI 30.7 to 50.6) per 1000 game hours.

Comparison between two floor types

Of the total of 62 injuries, 36 injuries occurred on artificial floors and 26 on wooden floors. The injury incidence per 1000 game hours was 59.9 (95% CI 43.2 to 83.0) on artificial floors versus 26.8 (95% CI 18.2 to 39.3) on wooden floors. Unadjusted IRR of all traumatic injuries was 2.2 (95% CI 1.4 to 3.7, p = 0.002) on artificial floors compared with that on wooden floors.

Unadjusted lower limb IRR was 2.1 (95% CI 1.2 to 3.7, p = 0.012) on artificial floors versus wooden floors. Unadjusted IRR of the most severe injuries was 3.6 times higher (95% CI 1.1 to 11.8, p = 0.032) and of non-contact injuries 13.7 times higher (95% CI 3.2 to 59.4, p < 0.001) on artificial floors. Seven of the knee injuries on artificial floors (7/8) were severe, while on wooden floors three severe knee injuries occurred (3/7). ACL rupture incidence per 1000 game hours was 5.0 (95% CI 1.6 to 5.5) on artificial floors versus 2.1 (95% CI 0.5 to 8.2) on wooden floors. Unadjusted ACL rate ratio was thus 2.4 (95% CI 0.4 to 14.5, p = 0.332) for artificial surfaces.

Table 3 shows the injury incidences and adjusted IRR between the two floor types. The effect of adjustment on the unadjusted IRR values was small.

DISCUSSION

The aim of the present study was to compare the incidence of traumatic floorball injuries between two surfaces: artificial floors and wooden floors. This study showed, for the first time, that the overall risk of traumatic injury for female floorball players is twofold higher on artificial floors than wooden floors. Moreover, the risk for severe injuries was clearly increased on the artificial surface.

Our study had several strengths. The information was collected prospectively producing good coverage of injuries and high accuracy of exposure times. The study physician interviewed the injured players and checked the accuracy of individual injury information. Each player kept a diary on her personal playing periods for each game, and information on the floor type (parquet or artificial floor) at each game was given by the Finnish Floorball Federation.

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Table 3 Number and incidence (per 1000 playing hours) of injury and adjusted IRR for two floor types

	Artificial floors		Wooden floors		IRR*	p Value
	n	Incidence	n	Incidence		
All traumatic injuries	36	59.9 (43.2 to 83.0)	26	26.8 (18.2 to 39.3)	2.1 (1.2 to 3.5)	0.005
Injury location						
Lower limb	27	44.9 (30.8 to 65.5)	21	21.6 (14.1 to 33.1)	2.0 (1.1 to 3.5)	0.022
Ankle	8	13.3 (6.7 to 26.6)	6	6.2 (2.7 to 13.7)	2.3 (0.8 to 6.6)	0.138
Knee	8	13.3 (6.7 to 26.6)	7	7.2 (3.4 to 15.1)	1.8 (0.6 to 5.1)	0.264
Spine and trunk	3	5.0 (1.6 to 15.4)	4	4.1 (1.5 to 10.9)	1.1 (0.2 to 5.0)	0.919
Head and neck	4	6.7 (2.5 to 7.7)	1	1.0 (0.1 to 7.3)	5.7 (0.6 to 53.6)	0.126
Upper limb	2	3.3 (0.8 to 13.3)	0	—	—	—
Injury type						
Sprain	17	28.3 (17.6 to 45.5)	13	13.4 (7.8 to 23.0)	2.0 (0.9 to 4.1)	0.065
Strain	7	11.6 (5.5 to 24.4)	3	3.1 (1.0 to 9.6)	3.7 (0.9 to 14.6)	0.062
Contusion	8	13.3 (6.7 to 26.6)	8	8.2 (4.1 to 16.4)	1.4 (0.5 to 3.8)	0.526
Fracture	0	—	2	2.1 (0.5 to 8.2)	—	—
Concussion	2	3.3 (0.8 to 13.3)	0	—	—	—
Nerve lesion	1	1.7 (0.2 to 11.8)	0	—	—	—
Laceration	1	1.7 (0.2 to 11.8)	0	—	—	—
Injury situation						
Contact	19	31.6 (20.2 to 49.6)	24	24.7 (16.6 to 36.9)	1.2 (0.6 to 2.2)	0.578
Non-contact	17	28.3 (17.6 to 45.4)	2	2.1 (0.5 to 8.2)	12.5 (2.9 to 54.9)	0.001
Injury severity†						
Minor	16	26.6 (16.3 to 43.4)	17	17.5 (10.9 to 28.2)	1.4 (0.7 to 2.9)	0.315
Moderate	11	18.3 (10.1 to 33.1)	5	5.1 (2.1 to 12.3)	3.3 (1.1 to 9.7)	0.029
Major	9	15.0 (7.8 to 28.8)	4	4.1 (1.5 to 11.0)	3.3 (0.9 to 10.9)	0.052

Injury incidence and adjusted IRRs are given with 95% CIs. IRR is obtained from Poisson model (p value from the z test). Significance level was <0.05.

*IRR for artificial floors versus wooden floors. The IRR was adjusted for age, body mass index, training volume, floorball experience and previous injuries.

†Injury severity: minor = time-loss 1–7 days, moderate = 8–28 days, major = more than 28 days.

The present study confirmed previous findings suggesting that high friction on artificial surfaces is an important risk factor for traumatic injuries. Powell and Schootman³ compared the injury rates between natural grass and AstroTurf surfaces in American football. They observed that the risk of knee ligament injuries is slightly increased on artificial turf (incidence density ratio = 1.13; 95% CI 1.00 to 1.27).

Orchard and Powell expanded the findings of Powell and Schootman by comparing injury rates between natural grass and AstroTurf surfaces in various weather conditions.¹¹ There was a reduced risk of ankle (relative risk = 0.69; 95% CI 0.58 to 0.83) and knee (relative risk = 0.77; 95% CI 0.66 to 0.91) sprains on natural grass compared with artificial turf. They also showed that cold weather is associated with lower knee and ankle injury risk in both natural grass and AstroTurf outdoor stadiums, probably because cold weather produced lower friction.

We compared injury incidences between two different floor types, which clearly differ from each other in the covering materials and friction properties. However, it must be taken into consideration that all the wooden floors and artificial floors are not similar. Freshly varnished and clean wooden floors can have higher friction than their older dusty counterparts. Also, friction between different artificial floors may vary. In general, however, the artificial floors clearly have higher friction than wooden floors.⁶

A second limitation of our study was that we did not have exact information on players' shoes, although it is known that four to five main shoe brands cover the market in floorball, and the players used the same shoes on both floor types. Ideally, each shoe model should be tested on different surfaces for exact information on friction.

Previous studies on surface-related injuries have focused mostly on outdoor sports. However, it is a well known fact that the risk of knee and ankle ligament injuries is especially high in indoor team sports such as basketball, team handball, volleyball and floor-

ball.^{9 10 12–15} Today plastic matting surfaces are commonly used in indoor sports venues, but the influence of different surfaces on injury rate in indoor team sports has scarcely been studied. As mentioned, Olsen and colleagues⁶ compared ACL injury rate between artificial and wooden floors in team handball and found more than twofold higher ACL risk for female players on artificial floors (odds ratio = 2.35; 95% CI 1.09 to 5.07). Our findings were similar. It seems that the shoe-surface interaction can be a considerable extrinsic risk factor for traumatic injury of lower limbs.

In this context it is, however, important to keep in mind that injuries in pivoting sports, particularly of the knee and ankle, are

What is already known on this topic

- Floorball is a sport that often results in traumatic injuries, the knee and ankle being the most commonly injured sites.
- High friction has been suggested to be an important risk factor of traumatic injuries in pivoting sports such as American football or team handball.
- Use of artificial surfaces has increased in floorball venues in recent years. However, the influence of floor type on injury risk has not been investigated in floorball.

What this study adds

- The incidence of traumatic floorball injuries is two times higher on artificial floors than on wooden floors.
- The risks for non-contact and severe injuries were 12-fold and threefold higher, respectively.

seldom a result of any single risk factor. Greater and more precise information on sports-specific risk factors, including measurements of friction characteristics and injury mechanisms, are needed for effective injury prevention.

CONCLUSION

The present study showed that the risk of traumatic injury among female floorball players is twofold higher when playing on artificial than wooden floors. Moreover, the rate of severe injuries was especially high on artificial floors. To control the increasing burden of injuries in pivoting sports, the role of shoe-surface friction in injury aetiology should be better acknowledged.

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Neuromuscular training and the risk of leg injuries in female floorball players: cluster randomised controlled study

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ABSTRACT

Objective To investigate whether a neuromuscular training programme is effective in preventing non-contact leg injuries in female floorball players.

Design Cluster randomised controlled study.

Setting 28 top level female floorball teams in Finland.

Participants 457 players (mean age 24 years)—256 (14 teams) in the intervention group and 201 (14 teams) in the control group—followed up for one league season (six months).

Intervention A neuromuscular training programme to enhance players' motor skills and body control, as well as to activate and prepare their neuromuscular system for sports specific manoeuvres.

Main outcome measure Acute non-contact injuries of the legs.

Results During the season, 72 acute non-contact leg injuries occurred, 20 in the intervention group and 52 in the control group. The injury incidence per 1000 hours playing and practise in the intervention group was 0.65 (95% confidence interval 0.37 to 1.13) and in the control group was 2.08 (1.58 to 2.72). The risk of non-contact leg injury was 66% lower (adjusted incidence rate ratio 0.34, 95% confidence interval 0.20 to 0.57) in the intervention group.

Conclusion A neuromuscular training programme was effective in preventing acute non-contact injuries of the legs in female floorball players. Neuromuscular training can be recommended in the weekly training of these athletes.

Trial registration Current Controlled Trials
ISRCTN26550281.

INTRODUCTION

Physical activity and exercise are beneficial for health.¹ Participation in competitive and recreational sports, however, increases the risk of injury.²

Acute injuries of the legs, especially those affecting the ankle and knee joints, are a common and serious problem in pivoting team sports³⁻⁷ such as handball, basketball, and floorball—sports that include plant and cut movements, sudden accelerations, stops, and turns—often causing long term harms for the player. Ankle injuries recur easily^{3,8,9} and severe knee injuries often lead to the early development of osteoarthritis.^{10,11}

Several studies have shown that a neuromuscular training programme can reduce the risk of ankle and knee injuries among athletes,¹²⁻¹⁸ whereas intervention studies found no decline in risk of injury in the training group.^{19,20} A problem in interpreting these results is that the methodological quality of the interventions has been heterogeneous.²¹

Floorball has become a popular sport in Europe during the past decade.^{6,22-24} It can be described as hockey played indoors on a court (20 m × 40 m) surrounded by a low board. Floorball results in many injuries, with the knee and ankle joints being the most commonly affected sites^{6,22-24}; 59% of acute ankle injuries and 46% of acute knee injuries occur through non-contact mechanisms.²⁴ We investigated whether a systematic neuromuscular training programme could reduce the risk of acute non-contact leg injuries in female floorball players.

METHODS

On the basis of a recent study of injuries during floorball²⁴ we estimated an incidence of 0.6 leg injuries per person year. Our power calculation for this cluster randomised study was based on the assumption that we would detect a 50% reduction in the incidence of leg injuries, from 0.6 injuries per person year in the control group to 0.3 per person year in the intervention group. We set the statistical power to 0.80, the significance level to 0.05, and the coefficient of variation of incidence rate between clusters (at team level) to 0.04. Thus we estimated that we would need to recruit a minimum of 344 players from 24 teams for a follow-up of six months.

Participants and randomisation

During April and May 2005 we invited 36 female floorball teams in Finland to participate in this study. Twenty eight agreed. Informed consent was sought from each player. We included players if they were official members of the participating teams and had no major injury at study onset. Of 477 players who agreed to participate, 457 were eligible for the study.

Using the team as the unit of randomisation we carried out stratified cluster randomisation to the intervention and control groups at league level (elite

Neuromuscular training programme

Running exercises (5-7 minutes)

Each training session starts with two minutes' jogging (20 m distance back and forth), then three to four minutes of eight running technique exercises, which are listed below (1 or 2 repetitions each of 20 m distance). The running exercise session ends with a speed run (2-3 repetitions of 20 m distance)

- Carioca running
- Sideways gallop
- Zigzag running forward
- Zigzag running backwards
- Skipping
- Walking lunges \times 4-8 steps and slow forward running
- Slow alternate bounding
- Combination hops (right-right-left-left-right-right)

Balance and body control exercises (5-7 minutes): one of three exercises

Squat technique with stick (either double or single leg)

- Double leg—2-3 \times 10-15 repetitions
- Single leg (right and left)—2-3 \times 8-10 for right leg and 8-10 repetitions for left leg

Balance exercise with medicine ball

- Single leg (right and left)—2-3 \times 4-6 for right leg and 4-6 throws for left leg

Balance board exercise (double or single leg)

- Double leg: with or without stick or ball—2-3 \times 20-30 seconds
- Single leg (right and left): with or without stick or ball—2-3 \times 20-30 seconds for right leg and 20-30 seconds for left leg

Plyometrics (5-7 minutes): one of three exercises

Forward jumps (double or single leg)

- Double leg jumps—2-3 \times 3-5 repetitions
- Single leg hops (right and left)—2-3 \times 3-5 for right leg and 3-5 repetitions for left leg

Jumps in place

- Three alternative exercises (lateral skate leap, split squat jump, or cycled split squat jump)—2-3 \times 8-12 repetitions

Jumps over stick or sticks (double or single leg)

- Double leg: three alternative exercises (backward and forward jumps, lateral jumps, or three dimensional jumps)—2-3 \times 8-12 repetitions
- Single leg (right and left): three alternative exercises (backward and forward hops, lateral hops, or three dimensional hops)—2-3 \times 4-8 for right leg and 4-8 repetitions for left leg

Strengthening exercises (5-7 minutes): one exercise for lower legs and one for core stability

Double leg squat with partner on back—2-3 \times 8-12 repetitions

Single leg split squat (right and left)—2-3 \times 4-8 for right leg and 4-8 repetitions for left leg

Nordic hamstrings—2-3 \times 4-8 repetitions

Isometric side and front bridge (right side and front and left side)—2-3 \times 10-30 seconds for right side, 10-30 seconds for front, and 10-30 seconds for left side

Cross curl-up (right and left)—2-3 \times 10-20 for right side and 10-20 repetitions for left side

Stretching exercises (5 minutes): for players with limits on low back function and flexibility

The exercises were introduced during the first two weeks of training. After that the players were advised to carry out the exercises in their own time

Seated hip and low back neutral zone exercise—2-3 \times 20 seconds

Hamstring stretch (right and left)—1-2 \times 20 seconds for right and 20 seconds for left

Kneeling hip flexor stretch (right and left)—1-2 \times 20 seconds for right and 20 seconds for left

league and first division and second division). We controlled for floor composition (artificial or wooden) of the training venue of each team. The statistician (MP) who carried out the computer generated randomisation was not involved in the intervention.

We informed the teams allocated to the intervention group about the upcoming training programme for preventing injuries. Teams in the control group were asked to do their usual training during the study period; after the study they received the same training programme and equipment as the intervention group.

Intervention

The neuromuscular training programme was developed by the medical and sports coaching staff of the UKK Institute. The feasibility of the programme was tested in one female floorball team during the summer preceding the intervention. The intervention took place between 1 September 2005 and 28 February 2006. At the start of the intervention period we educated one or two team members (coach, physiotherapist, or player) from each intervention group on how to use the training programme with their team. Each intervention team was provided with an instruction booklet, eight balance boards (disc diameter 35 cm; Fysioline, Tampere, Finland), eight balance pads (50 \times 41 \times 6 cm; Alcan Airex, Sins, Switzerland), eight medicine balls (ball diameter 28 cm, weight 1 kg, Togu Gebr Obermaier, Prien-Bachham, Germany), and an exercise diary. During the intervention period the educated instructors kept a diary of scheduled neuromuscular training sessions (content and duration of a session and number of participants).

The programme was designed to enhance players' motor skills and body control as well as to activate and prepare the neuromuscular system for sports specific manoeuvres. The programme consisted of four exercises: running techniques, balance and body control, plyometrics, and strengthening exercises (box and fig 1). In addition, players who had difficulties with control of the lower back or limits on flexibility did stretching exercises for the first two weeks of training. They were also advised to continue these exercises in their own time. Each exercise had different variations, with diverse difficulty and intensity. The main point of each exercise was to focus on proper techniques such as good posture, neutral zoning of lumbar spine, core stability, and positioning of the hip and knee, especially "knee-over-toe." The aim of the training was to improve control of the back, knees, and ankles during sports specific manoeuvres (running, cutting, stopping, standing) and thereby reduce the risk of injuries. Players worked in pairs and were guided to look at each other's technique and to give feedback during training.

The neuromuscular training sessions were carried out just before the floorball exercises, with a warm-up of low to moderate intensity for each exercise. One session lasted 20-30 minutes, with each exercise taking about five to seven minutes. The training was divided into four periods during the floorball season: two intensive training periods, which contained

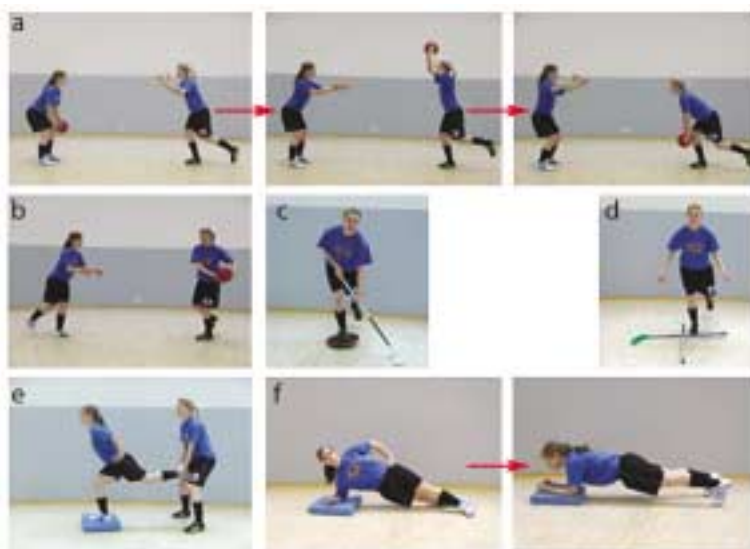


Fig 1 | (a) Balance exercise with medicine ball (assistant stands on two legs and player on one leg; assistant throws ball to player, who catches ball overhead and returns it below knee); (b) balance exercise with medicine ball (on one leg players throw and catch ball from side of body); (c) balance board exercise with stick and ball on one leg; (d) three dimensional leg hops over sticks; (e) leg split squat; and (f) isometric side and front bridge

neuromuscular training twice or three times a week, and two maintenance training periods with one training session in the weekly programme. Intensive training took place at the start of the season and during the break from games in December. Over the competitive season the neuromuscular exercises were followed through with maintenance training.

Table 1 | Characteristics of female floorball players receiving neuromuscular training programme (intervention group) or usual training (control group). Values are number (percentage) of players unless stated otherwise

Characteristic	Intervention group (n=256)	Control group (n=201)
Mean (SD) age (years)	24.2 (5.0)	23.3 (4.8)
Mean (SD) height (cm)	165.8 (5.1)	166.4 (5.3)
Mean (SD) weight (kg)	62.6 (8.0)	63.3 (8.1)
Mean (SD) body mass index (kg/m ²)	22.7 (2.5)	22.8 (2.4)
Mean (SD) floorball experience (years)	7.1 (3.1)	7.3 (3.0)
Mean (SD) preseason training*	7.5 (3.1)	7.8 (3.5)
Previous orthopaedic operations	66 (26)	36 (18)
Preseason leg injuries†:		
Ankle ligament	10 (4)	12 (6)
Knee ligament	1 (<1)	3 (1)
Muscle strain	8 (3)	3 (1)
Overuse	13 (5)	13 (6)
Total	32 (13)	31 (15)
Mean (SD) total exposure time (hours) during season‡:		
Training§	119.5 (30.9)	117.8 (29.4)
Game¶	6.8 (2.3)	6.7 (2.3)
Total	126.3 (32.5)	124.5 (30.8)

*Hours spent a week in sports four months before study.

†Occurring in four months before study.

‡Hours spent during six months' follow-up in structured training and playing.

§Hours spent during six months' follow-up in structured training (floorball and other).

¶Active game hours spent during six months' follow-up in structured floorball games.

Outcome measures

The primary outcome was an acute leg injury that occurred in non-contact circumstances (no contact with other player, stick, or ball). A secondary outcome was any injury to the legs (overuse injuries included). We defined an injury as acute if it occurred during a scheduled floorball game or practice, preventing the player from participating in a game or practice session for 24 hours. The severity of injuries was defined according to Ekstrand and Gillquist²⁵: minor injury—an injury causing absence from practise for 1-7 days; moderate injury—an injury causing absence from practise for 8-28 days; major injury—an injury causing absence from practise for more than 28 days.

Data collection

At baseline, players completed a questionnaire on background information, including anthropometrics, previous injuries, experience with floorball, and preseason training volume. During follow-up each coach recorded the players' scheduled practice and game hours on an exercise diary and noted all injured players. Injuries were recorded using a structured questionnaire. Injured players recorded the time, place, cause, type, location, and severity of the injury. After each follow-up month the coach mailed the diaries and questionnaires to the study doctor (TM). The study doctor contacted players after each new injury and checked the accuracy and consistency of the questionnaire data. She was responsible for the data collection but was not involved in the intervention. The player was defined as injured until she was able to train and play floorball again. At the end of the season all players filled in a questionnaire on injuries and subjective participation in the study to check the completeness and coverage of data collection.

Statistical analysis

We expressed the incidence (95% confidence interval) of injury as the number of injuries per 1000 hours of floorball practise and play. One way analysis of variance was used to estimate the intracluster correlation coefficients of incidence rates for injury. The unadjusted and adjusted incidence rate ratio between the two groups (intervention *v* control) was obtained from two level Poisson regression models. We considered a P value <0.05 to be significant. In the data analysis by multilevel modelling we took the cluster randomisation into account. Adjustments were done by individual level (age, body mass index, experience of floorball, playing position, and number of orthopaedic operations) and team level (league level and previous incidence of injuries). We did analyses according to the intention to treat principle. In addition to the intention to treat analyses, we carried out efficacy analyses to evaluate the potential benefits of high compliance and adherence to training (high indicating those teams that carried out the neuromuscular training at least three times a week during the first intensive period, at least twice a week during the second intensive period, and at least once a week during the

maintenance periods). We used the MLwiN (version 2.02) software package for multilevel analyses.

RESULTS

Figure 2 shows the flow of teams and players through the study. The consent rate for participation was high (86% of players from 28 teams) and the dropout rate low (5%). Twenty one players dropped out during the study period because of severe injury: nine from the intervention group (eight knee ligament ruptures and one rotator cuff rupture of the shoulder) and 12 from the control group (six knee ligament ruptures, four ankle ligament ruptures, and one lumbar disc prolapse). Data from these players were included in the analyses for the time they participated.

The players in both groups were similar for age, body mass index, experience of floorball, and scheduled hours spent in training and play (table 1). No significant differences were found between the groups in number of previous injuries, operations, or preseason training volume. Five teams (36%) in the intervention group used the training programme according to schedule, six (43%) had some irregularities in training, and three (21%) interrupted training during follow-up. Table 2 shows the training volume of the intervention teams. A mean 74% of the intended training sessions were carried out as planned.

Participation in the intervention during the first intensive and maintenance periods was more active than during the second periods (table 3). Irrespective of adherence to the intervention, all teams continued data

Table 2 | Compliance of female floorball teams (n=14) receiving neuromuscular training intervention

Variable	Mean (SD, range) volume of training
No of training sessions*	31 (12, 2-45)
% of players attending training	69 (15, 42-96)
Duration (minutes) of training session	24 (4, 19-32)

*Target number of sessions was 42 per team during season.

collection to the end of the study. Some of the players in the control group also did neuromuscular exercises during the study period: running technique, strengthening exercises, plyometrics, and balance board exercises (table 4). The number and frequency of these exercises were lower than in the intervention group.

Injury incidence

Overall, 32 327 scheduled hours of training and play was reported for the intervention group during the season, with a total of 87 leg injuries compared with 25 019 hours of training and play and 102 leg injuries in the control group.

Significantly fewer non-contact leg injuries (adjusted incidence rate ratio 0.34, 95% confidence interval 0.20 to 0.57, $P<0.001$; table 5) occurred in the intervention group than in the control group. The overall risk of leg injury was significantly different between the groups, favouring the intervention (adjusted incidence rate ratio 0.70, 0.52 to 0.93, $P=0.016$). This difference was due to a reduction in non-contact leg injuries as no differences were found between the groups for acute contact injuries or overuse leg injuries.

Six ruptures of the anterior cruciate ligament occurred in the intervention group, of which three were non-contact injuries, compared with four ruptures of the anterior cruciate ligament in the control group, of which three were non-contact injuries.

In efficacy analysis, intervention teams with high compliance and adherence to the neuromuscular training had a lower risk of injury than the control group: the incidence rate ratio between the high compliance group and control group for non-contact leg injury was 0.19 (95% confidence interval 0.06 to 0.64, $P=0.007$), for non-contact ankle ligament injury was 0.19 (0.05 to 0.82, $P=0.026$), and for non-contact knee ligament injury was 0.32 (0.04 to 2.59, $P=0.284$).

DISCUSSION

A neuromuscular training programme was effective in preventing acute non-contact leg injuries in female floorball players. The programme, aimed to enhance motor skills and body control, reduced the risk of leg injury by 66%. The intervention focused on improving the players' motor skills and body control as well as preparing the neuromuscular system for sports specific manoeuvres. The programme was designed to reduce the incidence of acute non-contact leg injuries, which are common in floorball. Compared with the control

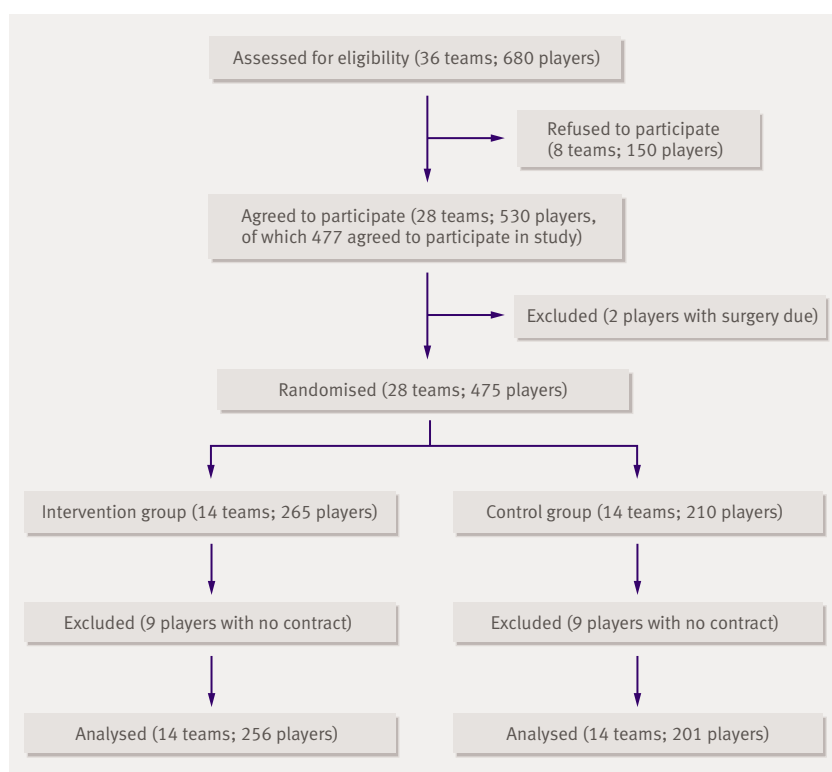


Fig 2 | Flow of teams and players through study

Table 3 | Number (percentage) of female floorball players in intervention group participating in scheduled neuromuscular training during each training period

Frequency of training sessions	First training period		Second training period	
	Intensive (6 weeks)	Maintenance (8 weeks)	Intensive (4 weeks)	Maintenance (8 weeks)
1-3 times weekly	211 (82)	182 (71)	110 (43)	119 (46)
2 or 3 times monthly	9 (4)	30 (12)	16 (6)	37 (15)
≤1 monthly	10 (4)	16 (6)	41 (16)	25 (10)
None	26 (10)	28 (11)	89 (35)	75 (29)
Total	256 (100)	256 (100)	256 (100)	256 (100)

group that received usual training, the intervention group had significantly fewer injuries. A reduced injury rate was found overall for leg injuries as well as for acute non-contact leg injuries. The greatest effects were observed in non-contact injuries of the ankle ligament.

Some studies have indicated that neuromuscular training probably plays a crucial part in the prevention of injuries¹²⁻¹⁸ and this intervention study supports these findings. In one study a multiple training programme for six weeks in high school sports teams reduced the rate of serious knee ligament injuries as well as the rate of non-contact knee ligament injuries.¹³ Another study showed that a structured warm-up programme among young handball players reduced the risk of traumatic knee and ankle injuries and the overall risk for severe and non-contact injuries.¹⁷ We found similar reductions in the risk of non-contact leg injuries, but when we analysed injuries by location, the risk of only ankle injuries reached statistical significance. The 51% reduction in non-contact knee ligament injuries did not reach significance, but the trend was parallel to that of overall non-contact leg injuries.

Strengths and limitations of study

Our study had some limitations. Firstly, the potential for not achieving double blinding in this type of study limits the strength of the conclusions. The randomisation phase, data collection, and data analysis were blinded, but for obvious reasons the coaches and players could not be blinded. Secondly, the sample size was sufficient for analyses of non-contact leg injuries but too small for detailed analysis of anatomical subgroups.

The study had many strengths. The validity of the data was high as 86% of eligible players from 28 floorball teams could be recruited. In addition, the intervention and control groups were similar for baseline characteristics, dropout rate, and training and play during follow-up. Compliance in collecting the data on exposure and injuries was also good.

The neuromuscular training programme was a modified combination of interventions from previous studies, and the exercises were easy to learn. The programme was designed to reduce the incidence of acute non-contact leg injuries. Contact injuries, caused by contact with another player, stick, or ball, are also common in floorball²⁴ although more difficult to prevent.

The training programme included many different exercise manoeuvres with several variations so it was not possible to determine which particular manoeuvre was effective in preventing injury. The determination of type of injury may not, however, be necessary, because floorball, as with all other team sports, includes a wide variety of fast and dynamic movements. To obtain proper body control and correct technique in sports specific manoeuvres, it would probably be wise to practise the required skills by noticeably varying the tasks. Also, standardisation of neuromuscular training is likely to be a key to injury prevention. To maintain the preventive effect we recommend the inclusion of varied neuromuscular exercises in weekly training programmes all year.

Five teams (36%) from the intervention group carried out the programme regularly through the season. Six teams (43%) had irregularities in training and three (21%) interrupted training. On the basis of

Table 4 | Number (percentage) of female floorball players in control group (usual training) who did neuromuscular training during study period

Frequency of training sessions	Type of neuromuscular training			
	Running techniques	Balance board	Plyometrics*	Strength training†
1 or 2 times weekly	67 (33)	14 (7)	40 (20)	62 (31)
2 or 3 times monthly	51 (25)	9 (4)	43 (21)	55 (27)
≤1 monthly	34 (17)	28 (14)	48 (24)	28 (14)
None	49 (25)	150 (75)	70 (35)	56 (28)
Total	201 (100)	201 (100)	201 (100)	201 (100)

*Jump and hop training.

†Double or single leg squats.

Table 5 | Number and incidence (per 1000 practise and playing hours) of acute non-contact leg injuries and incidence rate ratio for female floorball players receiving neuromuscular training (intervention group) or usual training (control group)

Injury type	Intervention group (n=256)		Control group (n=201)		ICC	Unadjusted incidence rate ratio (95% CI)	P value	Adjusted incidence rate ratio* (95% CI)	P value
	No	Incidence (95% CI)	No	Incidence (95% CI)					
Non-contact leg	20	0.65 (0.37 to 1.13)	52	2.08 (1.58 to 2.73)	0.041	0.31 (0.17 to 0.58)	<0.001	0.34 (0.20 to 0.57)	<0.001
Ligament	15	0.48 (0.27 to 0.84)	38	1.52 (1.10 to 2.09)	0.033	0.31 (0.16 to 0.60)	<0.001	0.35 (0.19 to 0.64)	0.001
Ankle ligament	8	0.27 (0.11 to 0.64)	27	1.10 (0.71 to 1.70)	0.059	0.24 (0.09 to 0.65)	0.005	0.28 (0.12 to 0.67)	0.004
Knee ligament	7	0.22 (0.10 to 0.45)	11	0.44 (0.24 to 0.80)	0.004	0.49 (0.19 to 1.27)	0.143	0.49 (0.18 to 1.31)	0.155
Muscle strain	5	0.15 (0.06 to 0.37)	14	0.57 (0.29 to 1.12)	0.040	0.26 (0.09 to 0.72)	0.009	0.40 (0.12 to 1.32)	0.134

ICC=intracluster correlation coefficient for incidence of injury. Incidence rate ratio obtained from two level Poisson model. Level of significance was <0.05.

*Adjusted at individual level (age, body mass index, floorball experience, playing position, and number of orthopaedic operations) and team level (league, previous incidence of injuries). Cluster randomisation was taken into account in data analysis.

information in the exercise diaries and players' subjective estimation of participation, it seemed that training activity was highest during the first two training periods, after which it declined. The intervention teams were, however, included in analyses regardless of their intervention training activity and therefore the effect of the programme might be even higher than reported. The efficacy analysis confirmed that the risk of injury was lower among those teams that trained regularly.

Although severe knee ligament injuries, particularly injuries of the anterior cruciate ligament, are of concern in female floorball, this study could not analyse the effect of the neuromuscular warm-up programme on these injuries because there were too few such cases (three non-contact ruptures of the anterior cruciate ligament in both intervention and control groups). It is noteworthy, however, that none of these ruptures occurred among the five teams that trained regularly through the season.

During the study it became obvious that some players in the control group did similar exercises to players in the intervention group, because these

exercises are commonly used in sports training. Training among these controls did not reach the level of the intervention group, however, and if this partial contamination of the controls biased the results of the study it erred on the side of underestimating rather than overestimating the effect of the neuromuscular training on the risk of injury.

In the intervention a strong emphasis was placed on proper technical performance of every exercise. We considered it important that the intervention coaches and players had good knowledge of the correct training technique, typical mistakes in each exercise manoeuvre, and appropriate methods for their correction. We emphasised that training with incorrect technique was likely to result in improper motor skills and body control and might increase the risk of injury.

This intervention study focused on women floorball players in three top level leagues in Finland. Because floorball players have a similar pattern of leg injuries and injury mechanisms, the training programme could be effective in floorball in general including players that are male, young, or play for recreational purposes. Further studies are needed to verify the training effect in these groups.

As it is easier to learn motor skills while young, we recommend that regular neuromuscular training of floorball players should begin no later than age 12. Correction of poor motor technique may be more difficult in adulthood—at least the learning process takes substantially more time and repetitions than that in childhood.

In conclusion, a neuromuscular training programme was effective in preventing acute non-contact injuries of the leg in female floorball players. Such training should be included in the weekly training of this sport.

We thank the players, coaches, and instructors of each participating team and the physiotherapists who participated and the Finnish Floorball Federation.

Contributors: All authors conceived and designed the study. KP carried out the literature search, coordinated and managed the study, which included testing and refining the intervention and data collection. HH contributed to testing the intervention and educating the instructors, which was planned

WHAT IS ALREADY KNOWN ON THIS TOPIC

Floorball players have an increased risk of ligament injuries of the ankle and knee, and about half of these injuries occur in non-contact situations

Studies providing evidence for prevention of sports injuries have been methodologically limited

WHAT THIS STUDY ADDS

A neuromuscular training programme to enhance the motor skills and body control of female floorball players reduced the risk of leg injury by 66%

The risk of non-contact ankle and knee ligament injury could be reduced by 65%

Neuromuscular training is recommended to be included in the weekly training programme of floorball

with KP. TM collected the data and carried out preliminary preparations of the data. MP analysed and interpreted the data. KP wrote the first draft of the paper and all authors provided substantive feedback on the paper and contributed to the final manuscript. KP is guarantor.

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Effect of a neuromuscular warm-up programme on muscle power, balance, speed and agility - A randomised controlled study

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ABSTRACT

Objective: To investigate whether a six-month neuromuscular warm-up programme could improve muscle power, balance, speed, and agility.

Design: Cluster randomised controlled study.

Setting: 27 top level female floorball teams in Finland.

Participants: 222 players (mean age 24 years) – 119 in the intervention group and 103 in the control group were followed up for one league season (six months).

Intervention: A neuromuscular warm-up programme included sports specific running technique, balance, jumping, and strengthening exercises. The teams were advised to use the programme 1-3 times per week through the league season. One training session took approximately 25 minutes.

Main outcome measures: Performance tests were assessed before and after the six-month intervention including static jump, countermovement jump, jumping over a bar, standing on a bar, and figure-of-eight running.

Results: At six months, we found statistically significant between-groups differences in two outcome parameters: jumping over a bar (number of jumps in 15 sec), and standing on a bar (number of balance losses in 60 sec). Mean between-groups difference in the former was 2.3 jumps (95% CI 0.8 to 3.8, $p=0.003$) favouring the intervention group, and in the latter -0.4 balance losses (95% CI -0.8 to 0.0, $p=0.050$), again in the favour of the intervention group.

Conclusion: A neuromuscular warm-up programme improved the floorball players' sideways jumping speed and static balance. The exercises were also safe to perform and can thus be recommended for weekly training of floorball players.

Trial registration: The International Standard Randomised Controlled Trial Register, the registration number ISRCTN26550281.

INTRODUCTION

Floorball is a fast and intensive indoor team sport that is played on a court (20x40m) surrounded by a low board. Game can be characterised by many quick-moving situations such as sudden speed-ups, stops and turns, and contacts with other players. During these rapid movements the risk for ligament injuries of the knee and ankle is clearly increased¹.

In view of these findings, fitness requirements for floorball players are quite extensive. A player should be in good physical condition including adequate cardiovascular fitness for interval running, and excellent musculoskeletal fitness for sports specific fast motions. Therefore, enhancing and maintaining aerobic and anaerobic capacity, and neuromuscular performance (muscle strength and power, as well as body balance and coordination), are the keys to successful and injury-free sports career.

Thus, it is not surprising that training programmes for preventing sports injuries typically consist of neuromuscular exercises including agility, balance, jumping and strengthening components²⁻⁸. The training programmes have been designed to enhance players' body control and motor skills for sports specific rapid movements, and thereby improve lower extremity biomechanics and reduce the injury risk⁹⁻¹².

This study is a part of a large randomised floorball injury prevention trial⁷. The neuromuscular warm-up programme was designed to improve the running and jumping techniques, balance, and body control among Finnish top level female players. In the primary analysis of the trial, the programme proved to be effective in preventing non-contact leg injuries⁷, but the training effect on players' musculoskeletal performance was not assessed. In the present analysis we examined whether this systematic neuromuscular warm-up programme enhanced players' muscle power, balance, speed and agility.

METHODS

28 female floorball teams in Finland participated in the intervention study that extended from September 2005 to February 2006. During the summer 2005 we first arranged the baseline test schedule with the participating teams, and then in August 2005 the tests were performed at the training venue of each team. The tests were repeated on February 2006. The study was approved by the Ethics Committee of the Pirkanmaa Hospital District, Tampere, Finland.

Participants and randomisation

All healthy players who appeared on the baseline tests and who were official members of the participating teams were included in the study. Final participation was confirmed by the informed consent of each player. 347 players from 28 teams were tested during August 2005. Stratified cluster randomisation to the intervention teams and control teams was performed at three league level (Elite league, 1st division and 2nd division) using a team as the unit of randomisation. The statistician (MP) who ran the computer-based randomisation was not involved in the intervention. Teams allocated to the intervention group were informed about the upcoming warm-up programme for preventing injuries. Teams in the control group were asked to do their usual training during the entire study period.

Intervention programme

The neuromuscular warm-up programme consisted of four different types of exercises: 1) running technique exercises, 2) balance and body control exercises, 3) jumping exercises, and 4) strengthening exercises to the lower limbs and trunk. The neuromuscular training was carried out like a warm-up session just before floorball exercises, with low-to-moderate intensity for each exercise type. One warm-up session lasted 20-30 minutes, each exercise type taking about five to seven minutes. The teams were asked use the programme 1-3 times per week during the study period. An exact description of the intervention programme has been published previously⁷.

Test battery

The baseline and follow-up tests were performed during a training hour of each team in their own training venue. Six blinded research physiotherapists carried out the tests. Before the tests, the players warmed up 5 minutes by jogging on a floorball court. The test battery included five performance tests, and they were performed in the following order:

Static jump and countermovement jump

Two different types of vertical jump tests were performed: a static jump and a countermovement jump¹³⁻¹⁴. Both tests measured the maximal vertical jump height (cm): ie, the muscle power of the extensor muscles of the lower extremities. The electronic apparatus (New Test Powertimer, New Test, Oulu, Finland) including the contact mat computed the height of the jump (cm) by measuring the flight time with a digital timer. In *the static jump* the subject was asked to jump as high as possible on the contact mat, starting the jump from a static squatting position with a 90 degrees knee angle. In *the countermovement jump* the subject started a jump from standing upright and then making a countermovement (squat) before the vertical jump. In both jumps the best result of three trials was used in the analyses.

Jumping over a bar

The jumping over a bar test was used to assess the players' maximal jumping speed¹⁵. The subject was asked to do repeated sideways jumps as quickly as possible over a foamed plastic bar (length 50 cm, width 4 cm, and height 4 cm) that had been placed on the ground. The jumping time was 15 seconds and number of properly done two-leg jumps was recorded (i.e. one-leg steppings and jumps touching the bar were excluded). The stopwatch was started simultaneously with the starting signal and the ending signal finished the test. The better result from two trials was used in the analyses.

Standing on a bar

The standing on a bar test measured one-leg static balance¹⁶, the test thus measuring person's ability to control the stationary one-legged standing position. The subject was asked to stand with her dominant leg on a narrow bar (width 2cm, height 4cm, and length 50cm) for one minute. The stopwatch was stopped every time the subject touched the floor with the free foot and restarted when the balanced position was achieved again. The number of balance losses (and thus restarts) was the studied variable. The subject was allowed to use her unsupported arms for balance. The dominant leg was tested only once.

Figure-of-eight running

The figure-of-eight running test measured running agility¹⁶, the test measuring person's ability to move, accelerate, decelerate, and change direction effectively and quickly in a controlled manner. The subject was asked to run as fast as possible a figure-of-eight course. The course was marked with two vertical cones placed ten meters apart and the start/finish line was next to the first cone. The stopwatch was started simultaneously with the subjects' takeoff and was stopped when the subject completed the course and crossed the finish line. The time was recorded in seconds. The better result of two attempts was recorded.

Data collection

At baseline, players completed a questionnaire about background information including anthropometrics, previous injuries, floorball experience and preseason training volume. During the six-month study period, each team coach wrote-up players' scheduled practice and game hours on an exercise diary. In addition, the educated warm-up instructors kept a diary about the scheduled warm-up sessions in the intervention teams. Also possible injuries were recorded. After each follow-up month, the coach and instructor mailed the filled diaries to the UKK Institute.

Statistical analysis

The differences of follow-up test means (static jump, countermovement jump, jumping over a bar, standing on a bar, and figure-of-eight running) between two study groups (control vs. intervention) were analysed by multilevel regression models taken into account the hierarchical structure of data due to cluster randomisation. Adjustments were done by individual level (baseline test result, age, floorball experience, playing position, and number of orthopaedic operations), and team level (league level). Analyses were performed according to the intention to treat (ITT) principle. In addition to the ITT analyses, efficacy analyses were conducted to evaluate the potential benefits of high training compliance and adherence (high indicating the players who carried out the warm-up exercises at least once a week during the 6-month follow up). A p value <0.05 was considered statistically significant. The MLwiN (version 2.02) software package was used for statistical analyses.

RESULTS

Study population

Figure 1 gives details of the flow of teams and players through the study. Altogether 345 players and 28 teams were randomised. Of these, 123 players (36%) dropped out of the study, leaving 222 players and 27 teams for current analysis. Table 1 shows the characteristics of players in the two groups. No significant differences were found between the groups in baseline characteristics.

Table 1 Characteristics of players in two groups, given as mean (standard deviation)

Characteristic	Intervention group (n=119)		Control group (n=103)	
Age, yrs	24.2	(4.2)	23.3	(5.3)
Height, m	165.4	(4.9)	167.1	(5.6)
Weight, kg	62.6	(8.5)	63.7	(7.5)
BMI, kg/m ²	22.8	(2.7)	22.8	(2.3)
Floorball experience, yrs	7.4	(3.2)	6.9	(3.1)
Preseason training, hours per week*	8.0	(3.1)	7.8	(3.5)
Training and playing, hours during the season †	133	(36)	126	(30)
- Training hours ‡	126	(34)	119	(28)
- Playing hours ‡‡	7.1	(2.3)	7.0	(2.2)

* Hours per week spent in sports during four months before study

† Hours spent during the six-month follow-up in structured floorball training and playing

‡ Hours spent during the six-month follow-up in structured floorball training (floorball and other training, including intervention training)

‡‡ The active game hours (ie, the true playing minutes) in the official floorball games during the six-month follow-up

Training activity

Concerning the training compliance of the measured 13 intervention teams, five teams did the warm-up programme according to the plan, six teams had some irregularities in training, and two teams interrupted training during the follow-up. 71 players (60%) from intervention group participated in structured warm-up sessions at least once a week during the study season, 28 players (23%) trained irregularly, and 20 players (17%) stopped training before the midpoint of the follow-up. No injuries occurred in the intervention group during the warm-up sessions. Concerning the control teams, forty players (39%) had done weekly some of the intervention exercises as a part of their usual training.

Performance tests

The data on the five outcome parameters and results of multilevel analysis are presented in Table 2. At six months, both groups showed improvements in all performance tests. Statistically significant between-groups differences were found in two outcome parameters; i.e., jumping over a bar (number of jumps in 15 sec), and standing on a bar (number of balance losses in 60 sec). Mean between-groups difference in the former was 2.3 jumps (95% CI 0.8 to 3.8, $p=0.003$) favouring the intervention group, and in the latter -0.4 balance losses (95% CI -0.8 to 0.0, $p=0.050$) again in the favour of the intervention group. Improvements in the other outcomes did not differ significantly between the two groups.

In efficacy analysis between high compliance players ($n=71$) and control group ($n=103$) we found parallel results like in the main analysis (Table 3). In jumping speed the adjusted mean difference between high compliance players vs. control group was 1.1 jumps (95% CI -0.1 to 2.3, $p=0.08$), and

in static balance test the adjusted mean difference was -0.4 balance losses (95% CI -0.9 to 0.1, $p=0.10$).

Table 2 Baseline and follow-up test means and adjusted mean difference between two groups

	Baseline test	Follow-up test	Mean difference*		
	mean (sd)	mean (sd)	estimate	95% CI	p Value
Static jump (cm)					
Control group (n=103)	26.4 (4.3)	28.8 (4.2)			
Intervention group (n=115)	27.8 (4.7)	30.1 (5.3)	0.4	-0.6 to 1.5	0.43
Countermovement jump (cm)					
Control group (n=103)	28.1 (4.1)	30.8 (4.4)			
Intervention group (n=115)	29.7 (5.0)	32.0 (5.1)	0.2	-0.8 to 1.2	0.70
Jumping over a bar (no. of jumps in 15 sec)					
Control group (n=102)	43.4 (3.8)	45.7 (4.6)			
Intervention group (n=114)	43.6 (3.9)	47.9 (5.4)	2.3	0.8 to 3.8	0.003
Standing on a bar (no. of balance losses in 60 sec)					
Control group (n=102)	1.4 (2.2)	1.3 (2.1)			
Intervention group (n=118)	1.6 (2.8)	1.0 (1.8)	-0.4	-0.8 to 0.0	0.050
Figure-of-eight running (sec)					
Control group (n=100)	5.57 (0.30)	5.53 (0.29)			
Intervention group (n=114)	5.55 (0.28)	5.49 (0.28)	-0.01	-0.06 to 0.04	0.58

Significance level was <0.05 .

* Adjusted mean difference between the intervention group and control group. Adjustments were done at individual level (baseline test result, age, floorball experience, playing position, and number of orthopedic operations) and team level (league). The cluster randomization was taken into account in the data analysis.

Table 3 Efficacy analysis: baseline and follow-up test means and adjusted mean difference between high compliance players and control group

	Baseline test	Follow-up test	Mean difference*		
	mean (sd)	mean (sd)	estimate	95% CI	p Value
Static jump (cm)					
Control group (n=103)	26.4 (4.3)	28.8 (4.2)			
High compliance (n=68)	28.5 (5.0)	30.7 (5.7)	0.5	-0.7 to 1.8	0.39
Countermovement jump (cm)					
Control group (n=103)	28.1 (4.1)	30.8 (4.4)			
High compliance (n=68)	30.5 (5.3)	32.4 (5.6)	0.2	-0.8 to 1.2	1.36
Jumping over a bar (no. of jumps in 15 sec)					
Control group (n=102)	43.4 (3.8)	45.7 (4.6)			
High compliance (n=68)	44.1 (4.0)	47.1 (4.9)	1.1	-0.1 to 2.3	0.08
Standing on a bar (no. of balance losses in 60 sec)					
Control group (n=102)	1.4 (2.2)	1.3 (2.1)			
High compliance (n=71)	1.6 (2.8)	0.9 (1.7)	-0.4	-0.9 to 0.1	0.10
Figure-of-eight running (sec)					
Control group (n=100)	5.57 (0.30)	5.53 (0.29)			
High compliance (n=66)	5.50 (0.27)	5.47 (0.28)	-0.01	-0.07 to 0.05	0.75

Significance level was <0.05 .

* Adjusted mean difference between the intervention group and control group. Adjustments were done at individual level (baseline test result, age, floorball experience, playing position, and number of orthopedic operations) and team level (league). The cluster randomization was taken into account in the data analysis.

DISCUSSION

Participation in a structured six-month neuromuscular warm-up programme designed to enhance players' motor skills and prepare the body to upcoming floorball training turned out to improve static balance and sideways jumping speed in female floorball players. Concerning changes in vertical jumps and running speed and agility, there were no differences between intervention and control groups.

Neuromuscular training

Some studies have shown that neuromuscular training is likely to enhance athletic performance⁹⁻¹² and thereby improve lower extremity biomechanics and reduce injurious forces. The used programmes differ in type, intensity, frequency, and duration, and this fact probably has a remarkable effect on measured outcomes. Hewett and colleagues¹⁰ investigated effects of six weeks intensive and progressive jump and weight training program on landing mechanics and lower limb strength in female athletes. The training session lasted about two hours and it was repeated three times a week. After the training period, landing forces from jump decreased and knee control increased among the trained female athletes. In addition, vertical jump height and hamstring-to-quadriceps muscle torque ratios increased in the trained group.

Chimera and co-workers¹¹ evaluated the effects of jump training on muscle-activation strategies and performance of lower extremity during six weeks intensive plyometric training period. Experimental group of female athletes performed jump exercises two times per week and one training session took about 20-30 minutes. They found significant increase in preparatory adductor muscle firing, adductor-to-abductor muscle co-activation and quadriceps-to-hamstring muscle co-activation in the intervention group. Findings supported the importance of hip-musculature activation strategies for lower extremity control, which interact in biomechanics and reduce harmful forces.

Emery et al.¹² studied effectiveness of home-based balance-training programme among male high-school students. The training programme included two- and one-legged balance exercises with wobble board and trunk stabilization exercises. Students were advised to use balance-training programme daily for six weeks, one training session lasted about 20 minutes. Balance test battery included static balance test (one-legged standing on the floor) and dynamic balance test (one-legged standing on the balance pad). Improvements in static and dynamic balance during the follow-up were significantly greater in the intervention group than in the control group.

Our neuromuscular training programme included running technique, balance, jumping and strengthening exercises with several variations, and it was designed to replace the traditional warm-up before structured floorball training. The intensity in each exercise was low-to-moderate. Therefore it was obvious that this training might not improve all measured outcomes. The programme did not, for example, include exercises which aim to improve maximal vertical jump height. Systematic strength and power training, such as the one in Hewett et al's study¹⁰, are needed to improve muscle power. On the other hand, it was logical that warm-up exercises enhanced static balance and sideways jumping performance because every warm-up session included different variations of one-legged standing and rebound jump series.

Though these warm-up exercises did not improve all of the measured outcomes, we feel that they should be practiced before sports-specific training since they have been shown to be effective in injury prevention³⁻⁸. In the primary analysis of our large injury prevention trial the greatest reduction was found in ankle ligament injuries⁷. Thus, improvements in players' jumping speed and

static balance are likely to indicate improvements in ankle control and muscle function of the lower legs.

In efficacy analysis we did not find greater improvements among the high compliance players. However, it is noteworthy that the high compliance players ($n=71$) had slightly better baseline test results than other intervention group, which may intend that those regularly trained players may have higher training volume, better condition and neuromuscular performance in general. At the same time, those players who had lower baseline results had improved their neuromuscular performance by quite small amount of training. This may indicate that improvements in jumping speed and static balance are very easy to attain at the initial stage of training or among novice players, even with irregular training.

The main point in diverse warm-up exercises is to activate athletes' proprioception and motor control, and thereby prepare the neuromuscular system for upcoming sports training. If upcoming sport training or playing includes for example one-legged movements, upper body rotations and running in different directions, it would be reasonable to practice those manoeuvres during the warm-up session. Systematic warm-up exercises are also excellent way to learn and maintain motor skills for each sport. On this account, in the present intervention the main point in each exercise was to focus on proper technique, such as good playing posture, neutral zone of lumbar spine, trunk stability, and position and function of the hip, knee and foot (especially "knee-over-toe" position) during the sports-specific manoeuvres.

Test battery

The selected performance tests were done during the teams' training hour on their own training venue. We chose largely used field tests, which were feasible and easy to perform. In further intervention studies it would, however, be important to explore more precisely the effects of neuromuscular training to players' body part movements and muscle activation in sports specific manoeuvres, because insufficient joint control and side-to-side differences in lower extremity performance are associated with increased risk of sports injury¹⁸.

Limitations and strengths of the study

Our study had some limitations. First, although the randomization phase, data collection and data analysis were blinded, for obvious reason neither the coaches nor players could be masked. Second, though the initial rate to participate the tests was quite high, the general participation rate to the follow-up tests could have been better (Figure 1). The drop out rate in our study was 36% and this may have influenced in the results, although the proportion of drop outs was similar in both groups. In fact, it was a great challenge to arrange suitable testing times for all players in this amateur sport. Third, it was also obvious that some players in the control group used similar neuromuscular exercises as those in the intervention groups, because these exercises are commonly used in sports training. However, it is likely that the training volume and quality among these controls did not reach the level of the intervention group and if this partial contamination of the controls biased the results of the study it erred on the side of underestimating rather than overestimating the effect of the neuromuscular program.

Besides the limitations, our study also had many strengths. First, a randomized study design was robust and reduced the potential biases and thus increased the reliability of the results. Second, the intervention and control groups were similar in baseline characteristics, drop out rate, and training and playing exposure during the six-month follow-up. Third, the neuromuscular warm-up activity in the intervention group was good.

In conclusion, the used neuromuscular warm-up programme was effective in enhancing floorball players' sideways jumping speed and static balance. Besides, the neuromuscular warm-up exercises were safe to perform and can be thus recommended to be included in the weekly training of this sport.

Perspectives

Floorball players have an increased risk for non-contact ligament injuries of the ankle and knee. Fortunately, regular and structured neuromuscular exercises have been proven to be effective in reducing the risk for such injuries, and therefore, they are also widely recommended and used in various sports. However, only few studies have analyzed whether and how these exercises affect on musculoskeletal performance. The findings of the present study revealed that the neuromuscular warm-up program improved floorball players' static balance and sideways jumping speed, and above all, these exercises were safe to perform. Nevertheless, further studies are needed to clarify more specifically the effects of different components of the used neuromuscular training. Such studies should focus on sports-specific changes in motor control, skills and technique.

What is already known on this topic:

- * Non-contact ligament injuries of the ankle and knee are largely preventable by neuromuscular training, but only few studies have analysed performance tests as the explanatory variables for this assumption.

What this study adds:

- * A neuromuscular warm-up programme that replaced the traditional warm-up improved players' static balance and jumping speed.
- * The exercises were safe to perform and can thus be recommended for weekly training of floorball players.

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Competing interest

None declared.

Role of the sponsors:

None

Contributors

KP, JP, MP, and PK contributed to study conception and design. KP carried out the literature, coordinated and managed all parts of the study including the arrangements of baseline and follow-up tests and data collection. KP conducted education of the research physiotherapists for testing, data collection and preliminary data preparations. MP conducted data analyses and interpretation of data. KP wrote the first draft of the paper and all authors provided substantive feedback on the paper and contributed to the final manuscript. KP is guarantor.

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Figure legends

Figure 1 Flow of teams and players through the study

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Figure 1 Flow of teams and players through the study

