Tampere University

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Epidemiology and Risk Factors of Acute Knee And Ankle Injury in Youth Team-Sports Athletes

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ACADEMIC DISSERTATION
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Tampere, July 2021

Jussi

ABSTRACT

The identification of incidence and risk factors for sport injuries is essential before injury prevention strategies can be planned. Basketball and floorball are fast-paced indoor team sports with a high risk of acute knee and ankle injuries. These injuries are often severe, causing a long absence from sports. The first purpose of this thesis was to describe the incidence and characteristics of injuries in youth floorball (Study I). The second purpose was to investigate associations between lower extremity (LE) muscle strength, knee injury history and knee function and the risk of acute LE injuries in youth basketball and floorball athletes (Studies II–IV). The study cohort of this thesis comprised a total of 396 (211 male and 185 female) youth basketball and floorball athletes who participated in injury and exposure registration during the seasons 2011–2014. At the preseasons, the athletes completed a baseline questionnaire and muscle strength tests. The LE muscle strength measures included one-repetition maximum (1RM) leg press, concentric quadriceps and hamstrings isokinetic strength and isometric hip abduction strength. The baseline questionnaire includes questions on knee injury history and function. Knee function was measured using the Knee Injury and Osteoarthritis Outcome Score. Unadjusted and adjusted Cox regression models were used to analyze risk factors.

The first study revealed that the total injury incidence in youth floorball athletes was 2.1 (95% confidence interval [CI] 1.7–2.4) injuries per 1,000 player-hours. Injury incidences per 1,000 player-hours during games and practices were 26.9 (95% CI 20.1–33.6) and 1.3 (95% CI 1.0–1.5), respectively. The ankle (37%) and knee (18%) were the most commonly injured body parts, and joint/ligament sprain (54%) was the most common injury type. Eighty-six percent of knee and 77% of ankle ligament injuries occurred without direct contact with the involved LE. Female athletes had significantly higher game injury (incidence rate ratio 1.9, 95% CI 1.1–3.2) and joint/ligament injury rates (incidence rate ratio 1.7, 95% CI 1.1–2.7) compared to male athletes.

The second study revealed that lower maximal hip abduction strength increased the risk of any type of acute injury in the same knee in male youth athletes (hazard ratio [HR] for 1 standard deviation [SD] decrease = 1.8, 95% CI 1.0–3.2, P = 0.04). However, receiver operating characteristics (ROC) curve analysis showed an area

under the curve (AUC) of 0.66, indicating "poor" combined sensitivity and specificity of maximal hip abduction strength. None of the strength risk factors were associated with acute knee or anterior cruciate ligament injury risk in youth female athletes. Adjusted risk factor analyses for noncontact acute knee and anterior cruciate ligament injuries in male athletes were not performed due to the low number of these injuries.

In the third study, greater 1RM leg press and maximal isokinetic quadriceps strength were associated with an increase in the risk of any type of acute ankle injury in male youth athletes (HR for 1 SD increase = 1.6, 95% CI 1.1–2.4, P = 0.01, and 1.4, 95% CI 1.0–2.0, P = 0.04, respectively). In youth female athletes, greater 1RM leg press and difference between legs in maximal hip abduction strength increased the risk of noncontact acute ankle injury (HR for 1 SD increase = 1.4, 95% CI 1.0–2.0, P = 0.03, and 1.4, 95% CI 1.0–2.0, P = 0.03, respectively). However, ROC curve analyses showed AUCs of 0.57–0.64, indicating "fail" to "poor" combined sensitivity and specificity of these risk factors.

In the fourth study, a history of previous acute knee injury increased the risk of any type of acute and noncontact acute knee injury in youth female athletes by 2.6- and 2.4-fold, respectively (HR 2.6, 95% CI 1.3–5.2, P = 0.01, and 2.4, 95% CI 1.1–5.0, P = 0.03, respectively). However, ROC curve analysis showed an AUC of 0.61 for both injuries, indicating "poor" combined sensitivity and specificity of previous acute knee injury. None of the scores for the Knee Injury and Osteoarthritis Outcome Score subscales were associated with acute knee injury risk in youth female athletes. Adjusted risk factor analyses for acute knee injuries in male athletes were not performed due to the low number of these injuries.

Based on the findings of this thesis, first, injury prevention efforts in youth basketball and floorball athletes should be focused on acute ankle and knee injuries. Second, hip abductor strengthening exercises can be recommended for male youth athletes. In youth female athletes, it is important to maintain good hip abductor strength balance between the LEs. Greater LE extension strength measured by 1RM leg press increases the risk of acute ankle injury in both male and female youth athletes. Strong athletes are probably able to run and change direction faster than less strong athletes, and this may increase the mechanical forces directed to LEs. In addition, treatment and rehabilitation of the present knee injury and the secondary prevention of reinjury should be emphasized in youth pivoting sports athletes. Finally, none of the studied risk factors can be used alone as screening tools for an acute knee or ankle injury in these athletes. Correspondingly, more studies are needed on other risk factors and their combinations to allow better prediction of future LE injuries. This would facilitate effectively targeting preventive measures and programs.

TIIVISTELMÄ

Urheiluvammojen esiintyvyyden ja riskitekijöiden tunteminen luo perustan vammojen ehkäisystrategioiden suunnittelulle. Koripallo ja salibandy ovat nopeatempoisia urheilulajeja, joissa on korkea riski saada äkillinen polvi- tai nilkkavamma. Nämä vammat ovat usein vakavia ja niistä toipuminen sekä paluu urheiluun on usein hidasta. Tämän väitöskirjan ensimmäinen tavoite oli tutkia urheiluvammojen esiintyvyyttä nuorilla salibandypelaajilla (ensimmäinen osatyö). Toisena tavoitteena oli tutkia, onko alaraajojen lihasvoima yhteydessä äkillisiin polvi-, eturistiside- tai nilkkavammoihin ja toisaalta, onko aiempi polvivamma ja polven itsearvioitu toimintakyky yhteydessä äkillisiin polvivammoihin nuorilla koripallo- ja salibandypelaajilla (osatyöt 2–4).

Tutkimusryhmän muodostivat 396 nuorta koripallo- ja salibandypelaajaa (211 mies- ja 185 naispelaajaa). Pelaajien urheiluvammat sekä peli- ja harjoittelutunnit rekisteröitiin kausien 2011–2014 aikana. Ennen kausien alkua pelaajat täyttivät esitietolomakkeen ja tekivät alaraajavoimatestit. Alaraajavoimatestit olivat yhden toiston maksimaalinen (1RM) jalkaprässivoima, konsentrinen isokineettinen etu- ja takareisivoima sekä isometrinen lonkan loitonnusvoima. Esitietolomake sisälsi kysymyksiä aiemmista polvivammoista sekä polvien toimintakyvystä, jota mitattiin Knee and Osteoarthritis Outcome Score- kyselyllä. Riskitekijöiden analysoinnissa käytettiin vakioimattomia ja vakioituja Coxin regressiomalleja.

Ensimmäisessä osatyössä urheiluvammojen esiintyvyys nuorilla salibandyn pelaajilla oli 2.1 (95% luottamusväli [LV] 1.7–2.4) tuhatta peli- ja harjoitustuntia kohden. Peleissä vammariski oli 26.9 (95% LV 20.1–33.6) ja harjoituksissa 1.3 (95% LV 1.0–1.5) tuhatta peli- ja harjoitustuntia kohden. Nilkka- (37%) ja polvivammoja (18%) sattui eniten ja vammatyypeistä yleisin oli nivel/nivelsidevamma (54%). Polven nivelsidevammoista 86% ja nilkan 77% tapahtui ilman suoraa kontaktia loukkaantuneeseen alaraajaan. Naispelaajien riski loukkaantua peleissä oli merkitsevästi suurempi kuin miespelaajien (ilmaantuvuustiheyksien suhde 1.9, 95% LV 1.1–3.2). Naispelaajilla sattui lisäksi merkitsevästi enemmän nivel/nivelsidevammoja miespelaajiin verrattuna (ilmaantuvuustiheyksien suhde 1.7, 95% LV 1.1–2.7).

Toisessa osatyössä havaittiin, että miespelaajilla heikko lonkan maksimaalinen loitonnusvoima lisäsi riskiä saada mikä tahansa äkillinen polvivamma samaan polveen. Vammariski (HR) nousi yhtä loitonnusvoiman keskihajonnan [KH] laskua kohden 1.8-kertaiseksi (95% LV, 1.0–3.2, P = 0.04). ROC-analyysissä havaittu käyrän alainen pinta-ala oli 0.66, joten maksimaalisen lonkan loitonnusvoiman yhdistetty herkkyys ja tarkkuus tunnistaa loukkaantuvat pelaajat oli kuitenkin ”heikko”. Mikään tutkituista voimariskitekijöistä ei ollut yhteydessä äkillisiin polvi- tai eturistisidevammoihin naispelaajilla. Miespelaajien äkillisten polvi- ja eturistisidevammojen lukumäärä ei riittänyt vakioitujen riskitekijäanalyysien tekemiseen.

Kolmannessa osatyössä suurempi 1RM jalkaprässi- ja maksimaalinen isokineettinen etureisivoima lisäsivät miespelaajilla riskiä saada mikä tahansa äkillinen nilkkavamma. (HR yhtä KH:n nousua kohden 1.6, 95% LV 1.1–2.4, P = 0.01 ja 1.4, 95% LV 1.0–2.0, P = 0.04, vastaavasti). Naispelaajilla puolestaan suurempi 1RM jalkaprässivoima ja maksimaalisten lonkan loitonnusvoimien puoliero alaraajojen välillä lisäsivät riskiä saada ilman kontaktia syntynyt äkillinen nilkkavamma (HR yhtä KH:n nousua kohden, 1.4, 95% LV 1.0–2.0, P = 0.03 ja 1.4, 95% LV 1.0–2.0, P = 0.03, vastaavasti). ROC-analyysistä saadut käyrän alaiset pinta-alat olivat 0.57–0.64, joten näidenkin riskitekijöiden yhdistetty diagnostinen herkkyys ja tarkkuus oli “hylätty” tai “heikko”.

Neljännessä osatyössä aiempi äkillinen polvivamma lisäsi naispelaajilla riskiä saada mikä tahansa ja ilman kontaktia syntynyt äkillinen polvivamma 2.6- ja 2.4-kertaisesti, vastaavasti (HR 2.6, 95% LV 1.3–5.2, P = 0.01 ja 2.4, 95% LV 1.1–5.0, P = 0.03, vastaavasti). ROC-analyysistä saatu käyrän alainen pinta-ala oli 0.61 molemmille vammoille, joten myös aiemman äkillisen polvivamman yhdistetty herkkyys ja tarkkuus oli “heikko”. Minkään Knee and Osteoarthritis Outcome Score-alaluokan pisteet eivät olleet yhteydessä äkillisiin polvivammoihin naispelaajilla. Miespelaajien äkillisten polvivammojen lukumäärä ei riittänyt vakioitujen riskitekijäanalyysien tekemiseen.

Tämän väitöskirjan löydösten perusteella nuorten koripallo- ja salibandypelaajien urheiluvammojen ennaltaehkäisyssä kannattaa keskittyä äkillisiin nilkka- ja polvivammoihin. Lonkan loitonnosvoimaharjoitteita voidaan suositella nuorille miesurheilijoille. Nuorten naisurheilijoiden on tärkeä ylläpitää hyvä tasapaino alaraajojen välillä lonkkien loitonnusvoimissa. Suurempi alaraajojen ojennusvoima jalkaprässillä mitattuna lisää äkillisen nilkkavamman riskiä sekä nuorilla mies- että naisurheilijoilla. Vahvat urheilijat mahdollisesti juoksevat ja vaihtavat suuntaa nopeammin kuin heikommat joukkuetoverinsa, jolloin alaraajoihin saattaa kohdistua suurempia mekaanisia voimia. Lisäksi polvivammojen korkean uusiutumistaipumuksen vuoksi aiemman polvivamman huolellinen hoito ja kuntoutus on tärkeää nuorilla palloilijoilla. Tässä väitöskirjassa tutkittuja menetelmiä ei suositella käytettäviksi yksinään seulomaan nuorten urheilijoiden vammariskiä. Jatkossa tulee tutkia muitakin alaraajavammojen riskitekijöitä ja näiden yhdistelmiä, jotta voidaan paremmin ennakoida ja ehkäistä tulevat loukkaantumiset.

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ABBREVIATIONS

1RM	one-repetition maximum
ACL	anterior cruciate ligament
ADL	Activities of Daily Living
AUC	area under the curve
BMI	body mass index
CI	confidence interval
HR	hazard ratio
HQ	hamstrings to quadriceps
IRR	incidence rate ratio
KOOS	Knee Injury and Osteoarthritis Outcome Score
LE	lower extremity
MRI	Magnetic resonance imaging
PROFITS	Predictors of lower extremity injuries in team sports
QOL	Knee-Related Quality of Life
ROC	receiver operating characteristics
SD	standard deviation
Sport/Rec	Sport and Recreation

ORIGINAL PUBLICATIONS

I	Pasanen, K., Hietamo, J., Vasankari, T., Kannus, P., Heinonen, A., Kujala, U., Mattila V., & Parkkari, J. (2018). Acute injuries in Finnish junior floorball league players. *Journal of Science & Medicine in Sport*, *21*(3), 268-273.
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AUTHOR'S CONTRIBUTIONS

I	Hietamo J acted as a study physician and was responsible for collecting the injury data. Hietamo J carried out data analysis and interpreted the results. Hietamo J wrote the first version of the article. Pasanen K was the primary author of the article.
II	Hietamo J acted as a study physician and was responsible for collecting the injury data. Hietamo J carried out data analysis and interpreted the results. Hietamo J was the primary author of the article.
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1 INTRODUCTION

Participation in sport during adolescence not only develops athletic performance but also enhances general physical and mental well-being (Biddle & Asare, 2011; Hallal et al., 2006). Despite the benefits, participation in sport increases injury risk. The highest sport and recreation-related injury incidence has been reported in patients aged 10-19 years in Finnish hospital emergency departement (Lüthje et al., 2009). Participation in sports clubs in adolescence has also been found to be stronger risk factor for injury hospitalization than recurring drunkenness or daily smoking (Mattila et al., 2009).

Lower extremity injuries are common in worldwide popular team sports, such as soccer and basketball (Deitch et al., 2006; Kurittu et al., 2021; Lüthje et al., 2009). In youth athletes, the incidence of acute knee and ankle injury is high in these sports (Borowski et al., 2008; Clausen et al., 2014; Cloke et al., 2009; Ingram et al., 2008; Swenson et al., 2013). Acute knee and ankle injuries typically occur during athletic movements such as landings, rapid direction changes and cutting or twisting movements (Boden et al., 2000; McKay et al., 2001; Olsen et al. 2004; Woods et al., 2003). Knee ligament sprain is the most common type of acute knee injury in sport (Ingram et al., 2008). The rupture of the anterior cruciate ligament (ACL) is especially a serious injury that leads to long absence from sports or sport career termination, high risk of reinjury and early osteoarthritis (Oiestad et al., 2009; Wiggins et al., 2016). Lateral ankle sprain, as the most common type of ankle injury in sport (Doherty et al., 2014; Fong et al., 2007), can also lead to a marked loss of practicing and playing time (Cloke et al., 2009) and often evolves to persistent pain, weakness and chronic instability, possibly resulting in lower sport activity levels or even a change of sports (Anandacoomarasamy & Barnsley, 2005).

Floorball and basketball are popular team sports in Finland, with approximately 66,000 and 20000 licensed athletes, respectively. (www.floorball.fi; www.basket.fi). Floorball is a fast indoor sport, and floorball athletes' movement patterns have several similarities with those of basketball and soccer athletes. Studies in adult floorball athletes have also revealed a high knee and ankle injury risk (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001; Tranaeus et al., 2016). However, there are no previous studies investigating the incidence and characteristics of acute injuries in youth floorball athletes, and this was the first aim of this thesis.

Knowledge of injury risk factors is essential before planning injury prevention programs (Bahr & Krosshaug, 2005). Risk factors are traditionally divided into two main groups: internal (athlete-related) and external (environmental; van Mechelen et al., 1992). Complex interactions of these factors make an athlete susceptible to injury (Bahr & Krosshaug, 2005; Meeuwisse, 1994). An example of a widely studied internal risk factor is muscle strength. Lower hamstrings-to-quadriceps (HQ) strength ratio (Myer et al., 2009; Söderman et al., 2001), as well as lower hip external rotation and abductor strength (Khayambashi et al., 2016), has been associated with increased risk of ACL injury, whereas some other studies did not find such association (Nakase et al., 2020; Shimozaki et al., 2018; Steffen et al., 2016; Vacek et al., 2016). Lower hip extensor (De Ridder et al., 2017) and abduction strength (Powers et al., 2017) have also been demonstrated to increase the risk of lateral ankle sprain, but contrary results also exist (McHugh et al., 2006). Despite numerous studies, the role of muscle strength as a risk factor for acute knee or ankle injury is controversial. In addition, there is a limited number of studies concentrating especially on youth athletes. The second aim of this thesis was to investigate muscle strength as a potential risk factor for acute knee, ACL or ankle injury in youth floorball and basketball athletes.

As opposed to adult or professional athletes, health professionals and clinical testing equipment are usually rarely available to youth and nonprofessional athletes. Questionnaires could provide simple, feasible and time-saving instruments to identify athletes who are at increased risk of getting an injury. History of previous knee injury and lower scores in one or more Knee Injury and Osteoarthritis Outcome Score (KOOS) subscales have been associated with increased risk of any type of knee injury in youth soccer athletes (Clausen et al., 2016; Kucera et al., 2005; Steffen et al., 2008). However, findings concerning soccer athletes do not necessarily represent other youth team-sport athletes. The third aim of this thesis was to investigate previous acute knee injury and knee function as potential risk factors for acute knee injury in youth floorball and basketball athletes.

2 LITERATURE REVIEW

2.1 Definitions and methodology in sport injury research

According to a recent International Olympic Committee consensus statement, an injury can be defined as tissue damage or other derangements of normal physical function resulting from rapid or repetitive transfer of kinetic energy while participating in sports (Bahr et al., 2020). The injury may result directly or indirectly from participation in sport or may result from activities not related to sport (Bahr et al., 2020). The onset of sport injury has traditionally been classified as acute/traumatic/sudden onset or overuse/gradual onset injury (Fuller et al., 2006; Fuller et al., 2007; King et al., 2009; Pluim et al., 2009; Turner et al., 2012), although overuse injuries can also have "sudden" onset (Mountjoy et al., 2016; Orchard et al., 2016; Timpka et al., 2014). Acute injuries can result from direct contact, indirect contact or noncontact mechanisms (Bahr et al., 2020).

A recurrent injury can be defined as injury of the same type and in the same location as the first injury (Fuller et al., 2006). In a more precise definition, injuries are classified as index (first) and subsequent injuries. A subsequent injury of the same type and in the same location as the index injury can be defined as recurrent injury, and a subsequent injury in the same location but of a different type as the index injury is defined as subsequent local injury. Recurrent injuries can be classified as exacerbations (index injury not fully healed) and reinjury (index injury fully healed; Hamilton et al., 2011).

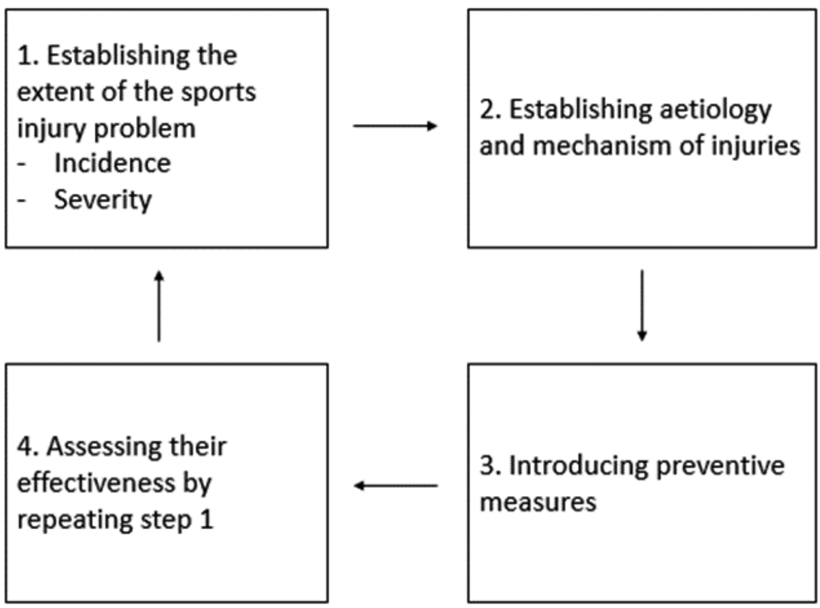
In sport injury research, classification of injury location, type and pathology are commonly based on sports medicine–specific coding systems—for example, the Orchard Sports Injury Classification System (Orchard et al., 2016) and the Sport Medicine Diagnostic Coding System (Meeuwisse & Wiley, 2007). A widely used injury severity measure is the duration of time loss, which is the number of days from the date of onset until the athlete can fully participate in sport (Fuller et al. 2006). A severe injury is defined as an injury resulting in over 28 days of absence (Fuller et al., 2006). However, the duration of time loss cannot always be defined clearly, especially for overuse injuries. Therefore, a scoring system based on the athlete's symptoms has been developed to register the severity of overuse injuries (Clarsen et al., 2013).

In addition, the severity of sport injury can be recorded based on the degree or urgency of medical attention (Schwellnus et al., 2019).

2.2 The theories of sport injury risk factor and prevention research

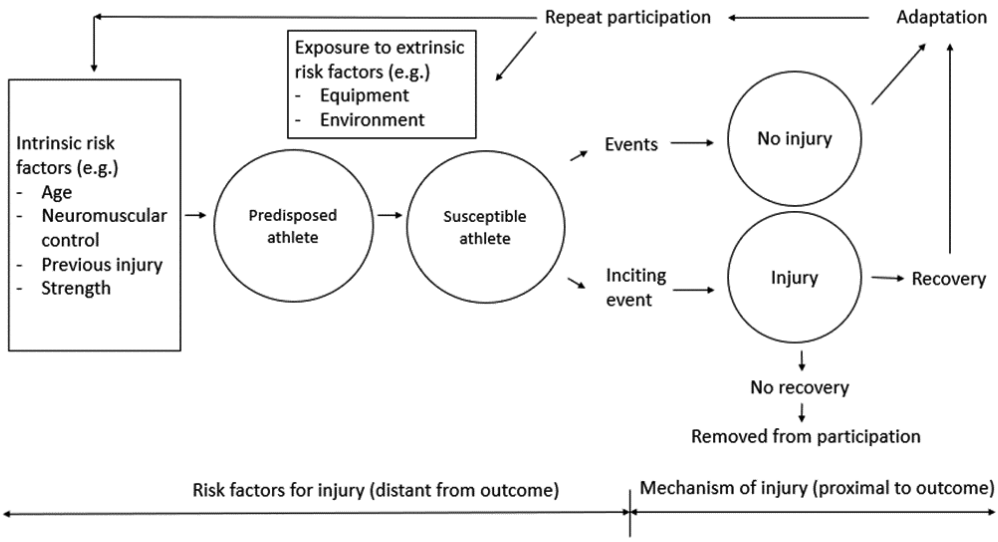
According to van Mechelen et al. (1992), injury prevention research comprises four sequences. In the first step, sport injury, as a problem, is identified and described in terms of incidence and severity. In the second step, factors and mechanisms that play a part in sport injury occurrence are identified. In the third step, measures that can reduce future sport injury risk are introduced based on the factors and mechanisms identified in the second step. In the fourth step, the effect of the measures introduced in the third step is evaluated by repeating the first step (Figure 1).

Figure 1. The four sequences of injury prevention research (adapted from van Mechelen et al., 1992)



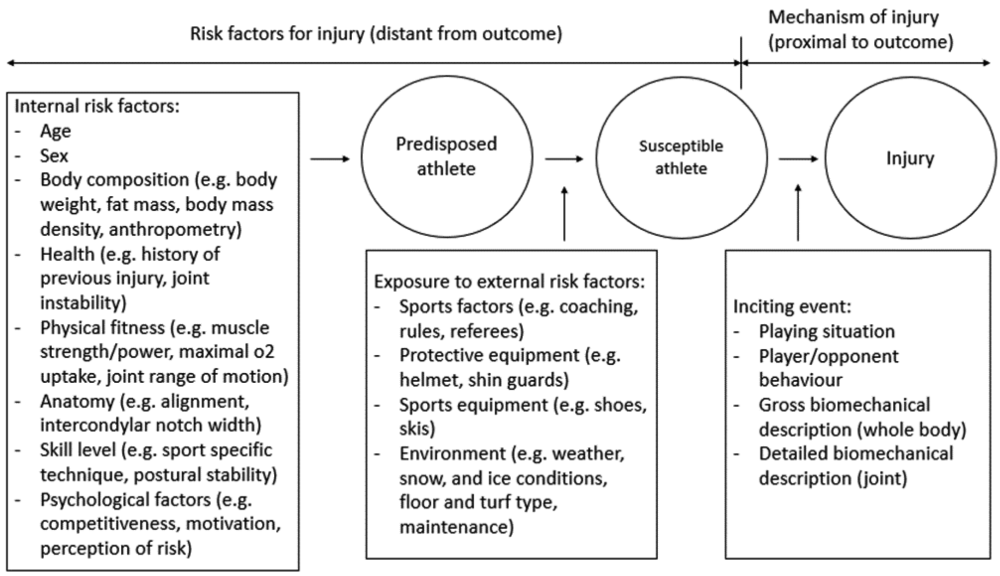
The most critical and challenging step of injury prevention research is the second step as the successful identification of injury risk factors and mechanisms forms the basis for effective preventive measures (Bahr & Krosshaug, 2005; van Mechelen et al., 1992). Meeuwisse (1994) developed an epidemiologic injury causation model, which formed the basis for epidemiological sport injury research. In this model, internal or intrinsic (athlete-related) risk factors predispose and external or extrinsic (environmental) risk factors make an athlete susceptible to injury before a single inciting event leading to injury occurs. Thus, the model indicates that an injury is a result of the complex interactions between the internal (such as age and sex) and external risk factors (such as field condition and equipment) and that the inciting event is only the last cause of injury. This epidemiological model was further developed to be more dynamic, taking into consideration that risk factors may change through the preceding cycles of participation as the exposure and possible injury produce adaptation or maladaptation (Figure 2; Meeuwisse et al., 2007).

Figure 2. The dynamic model of etiology in sport injury (adapted from Meeuwisse et al., 2007)



In a biomechanical injury causation model, injury is thought to result from a transfer of energy to the tissue and eventually caused by imbalance between mechanical load and load tolerance (McIntosh, 2005). In this model, the mechanical load and load tolerance are modified by behavior/attitude, training, skills, equipment, coaching, other competitors and the environment. The comprehensive injury causation model developed by Bahr and Krosshaug (2005) is based on epidemiologic and biomechanical models highlighting the importance of describing the injury mechanism (inciting event) on different levels: playing situation, athlete/opponent behavior, whole-body biomechanics and joint/tissue biomechanics (Figure 3). In a recent injury causation model, an injury is considered a result of complex, nonlinear interactions between interconnected determinants rather than linear interactions between isolated and predictive risk factors (Bittencourt et al., 2016a). In this model, the web of determinants can form observable regularities or risk profiles that may be related to the injury occurrence or adaptation.

Figure 3. Comprehensive injury causation model (adapted from Bahr & Krosshaug 2005)



2.3 Epidemiology of floorball injuries

Epidemiologic studies of floorball injuries have focused on adult athletes (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001; Tranaeus et al., 2016; Wikström & Andersson, 1997). The total (acute and overuse) injury incidence has been reported to be between 2.6 and 3.7 in male and 2.5 and 3.9 in female athletes per 1,000 player-hours (Pasanen et al., 2016; Tranaeus et al., 2016; Wikström & Andersson, 1997). Several studies have found higher injury incidence during games compared to practices for both sexes (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001). In four studies (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001; Wikström & Andersson, 1997), most injuries were acute, but one study reported overuse injuries being more common in male athletes (Tranaeus et al., 2016). The proportion of noncontact injuries has been found to be 45% of acute injuries in both sexes (Pasanen et al., 2008; Wikström & Andersson, 1997). The most frequent cause of contact injury has been reported to be body contact/collision with an opponent, regardless of sex (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001; Wikström & Andersson, 1997).

Most injuries affect the lower extremities (LEs), and overall, the ankle and knee are the most commonly injured body parts (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001; Tranaeus et al., 2016; Wikström & Andersson, 1997). Among acute injuries, joint/ligament sprain has been the most common injury type, followed by muscle/tendon strain and contusion (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001). Pasanen et al. (2016) found that 12% of all injuries in floorball were recurrent injuries. In addition, Wikström and Andersson (1997) reported that 50% of athletes with ankle sprain previously had a similar injury on the same ankle.

Regarding time loss from sport, most injuries have been minor (one to seven days of absence; Pasanen et al., 2008; Pasanen et al., 2016; Tranaeus et al., 2016). The proportion of severe (>28 days of absence) injuries has been reported to be 18%–22%, with the knee being the most commonly injured body part (Pasanen et al., 2008; Pasanen et al., 2016; Tranaeus et al., 2016).

2.4 Epidemiology of basketball injuries in youth athletes

There are several epidemiologic studies of basketball injuries in youth high school (Borowski et al., 2008; Messina et al., 1999; Powell and Barbell-Foss 2000) or collegiate (Agel et al., 2007; Dick et al., 2007; Meeuwisse et al., 2003) athletes from United States. The injury incidence has been reported to be 28 in males and 29 in females per 100 player-seasons (Powell and Barbell-Foss 2000) or 1.8 in males and 2.1 in females per 1,000 athlete-exposures (Borowski et al., 2008). Meeuwisse et al. (2003) found the injury incidence of 4.9 per 1,000 athlete-exposures in injuries resulting fewer than seven sessions time loss in male athletes. Few studies have reported the injury incidences per 1,000 player-hours. Messina et al. (1999) reported the total injury incidence of 3.2 in male and 3.6 in female and Yde and Nielsen (1990) 3.0 in a group of male and female adolescent basketball athletes. Pasanen et al. (2017) studied the same cohort of youth basketball athletes as in the present thesis and found that the incidence of acute time-loss injuries per 1,000 player-hours was 2.5 and 2.9 in males and females, respectively.

Several studies have shown that the injury risk is higher in games compared to practices in youth basketball athletes regardless of sex (Agel et al., 2007; Borowski et al., 2008; Dick et al., 2007; Messina et al., 1999). Contact injuries are common and contact with another player or ball seem to be the most frequent injury situation (Agel et al., 2007; Borowski et al., 2008; Dick et al., 2007; Meeuwisse et al., 2003; Pasanen et al., 2017; Yde and Nielsen 1990).

Approximately 60% of all and 80% of acute injuries affect lower extremity (Agel et al., 2007; Dick et al., 2007; Pasanen et al., 2017). In most studies, ankle and knee have been the most commonly injured body parts in both sexes (Agel et al., 2007; Dick et al., 2007; Meeuwisse et al., 2003; Messina et al., 1999; Pasanen et al., 2017), but Yde and Nielsen (1990) found that finger injuries occurred most commonly. As in floorball, joint/ligament sprain has been the most common injury type, followed by muscle/tendon strain and contusion (Borowski et al., 2008; Pasanen et al., 2017). Ankle ligament sprain and knee internal derangement have reported to be the most common injuries in games and practices and in both sexes (Agel et al., 2007; Dick et al., 2007). Pasanen et al. (2017) found that 46% of all acute injuries were lateral ankle sprains.

Approximately 10 % of all injuries (Powell and Barbell-Foss 2000), but almost one third of acute injuries (Pasanen et al., 2017) have reported to be recurrencies. The majority of injuries in both sexes have required fewer than 7-10 days of absence (Agel et al., 2007; Borowski et al., 2008; Dick et al., 2007; Powell and Barbell-Foss 2000). Knee injuries have found to be most often severe requiring over 10 days of absence (Agel et al., 2007; Dick et al., 2007). Meeuwisse et al. 2003 reported the average time loss of 18.3 days for knee injury in male athletes.

2.5 Risk factors for acute knee and ACL injury

2.5.1 Internal risk factors

Studies identifying risk factors for acute knee injuries have almost exclusively focused on ACL injury. There is strong consensus that the female sex is a risk factor for ACL injury (Agel et al., 2005; Arendt et al., 1999; Mihata et al., 2006; Powell & Barber-Foss, 2000; Walden et al., 2011a). Female athletes have been reported to sustain ACL injury at a younger age than male athletes (Walden et al., 2011b). The highest ACL injury rate seems to be in the late teens and early twenties in females and in mid-to-late twenties in male athletes (Serpell et al., 2012). In adolescence, the risk for acute knee (Hägglund et al., 2016) and ACL injuries (Shea et al., 2004) has been found to increase with age in female athletes.

There is evidence that a family history of ACL injury might predispose athletes to future acute knee (Hägglund et al., 2016) and ACL injuries (Flynn et al., 2005; Hägglund & Walden, 2016). Potential genetic risk factors for ACL injury have also been identified (September et al., 2012).

Sex hormones have been suggested to play a role in ACL injury in female athletes and partly explain the higher ACL injury incidence compared to male athletes. The highest risk for ACL injury in female athletes was found to be during the preovulatory phase of the menstrual cycle (Hewett et al., 2007).

Several anatomical variables have been proposed to increase the risk of ACL injury: increased general or anterior-to-posterior knee joint laxity, genu recurvatum/knee hyperextension, a greater quadriceps angle (an angle formed by a line directed from the central patella to the tibial tubercle), a smaller intercondylar notch width, a greater posterior slope of the tibia, greater femoral anteversion, increased foot pronation and navicular drop, and increased hamstrings flexibility (Alentorn-Geli et al., 2009; Hewett et al., 2006). In addition, greater height in male (Orchard et al., 2001) and greater body mass index in female athletes (Uhorchak et al., 2003) have been found associate with the risk of sustaining an ACL injury.

Several neuromuscular and biomechanical risk factors for ACL injury have been discussed (Alentorn-Geli et al., 2009; Hewett et al., 2006). Different neuromuscular activation patterns have been proposed as one reason for increased ACL injury risk in female athletes because increased quadriceps activation during landing and cutting movements have been found in female athletes compared to their male counterparts (Malinzak et al., 2001; Zazulak et al., 2005). In addition, Zebis et al. (2009) found, that lower preactivity of the semitendinosus and higher preactivity of the vastus lateralis were associated with an increased risk of ACL injury in female athletes.

According to video analyses, normalized (in relation to the hips) knee separation in drop jump (O'Kane et al., 2017) and a combination of increased lateral trunk motion angle and knee valgus angle in single-leg drop jump (Dingenen et al., 2015) were associated with increased risk of acute knee injury in female athletes. Increased knee valgus angle and abduction moment (Hewett et al., 2005), as well as medial knee displacement (Krosshaug et al., 2016), in drop jump have also been found to increase the risk of ACL injury in female athletes. In addition, decreased knee flexion angle and hip flexion range of motion, as well as increased external knee flexion moment and vertical ground-reaction force, have been associated with increased risk of ACL injury in female athletes (same cohort as in the present thesis; Leppänen et al., 2017a; Leppänen et al., 2017b).

2.5.2 Muscle strength

Acute noncontact knee and ACL injuries typically occur during landings, direction changes and cutting or twisting movements (Alentorn-Geli et al., 2009; Boden et al., 2000; Klein et al., 2020; Olsen et al., 2004) because of increasing varus/valgus and internal/external rotation moments (Besier et al., 2001). Video analyses have revealed that knee valgus loading, perhaps with concurrent tibial internal or femur external rotation, seems to be the primary mechanism of these injuries, regardless of sex or sport (Koga et al., 2010; Krosshaug et al., 2007; Olsen et al., 2004; Stuelcken et al., 2016; Walden et al., 2015). Flexion and extension moments and co-contractions generated by hamstrings and quadriceps muscles have been shown to prevent varus/valgus moments and thus stabilize the knee in response to perturbation and in sport-specific movements (Dhaher et al., 2003; Lloyd & Buchanan, 2001; Lloyd et al., 2005). Lower maximal hamstrings, quadriceps and hip abduction strength have been suggested to increase knee valgus load and thus acute knee and ACL injury risk (Claiborne et al., 2006; Jacobs et al., 2007; Weinhandl et al., 2014). Deficits in trunk control have also been suggested to increase knee valgus load (Hewett & Myer, 2011). In a recent meta-analysis, reduced hip and knee muscle strength were weakly and trunk muscle strength moderately associated with the increased knee valgus angle during weight-bearing activities (Cronström et al., 2016).

Three prospective studies have investigated the association between muscle strength and acute knee injury (Table 1). Although Bakken et al. (2018) found no association between any measured muscle strength variable and acute knee injury in the adjusted analyses, lower bilateral abductor squeeze strength at 45° was reported to increase the risk of this injury in the unadjusted analysis. In addition, in a case control study by Ryman Augustsson and Ageberg (2017), lower one-repetition maximum (1RM) barbell squat strength was reported to increase the risk of acute knee injury in female but not in male athletes from various sports. However, no association was found between 1RM back squat strength and knee sprain in a retrospective study of Japanese male American football athletes (Iguchi et al., 2016).

Several prospective studies have investigated the association between muscle strength and ACL injury (Table 1). Lower HQ strength ratio (Myer et al., 2009; Söderman et al., 2001), as well as lower hip abduction and external rotation strength

(Khayambashi et al., 2016), has been associated with increased risk of ACL injury in female athletes, but contrary findings also exist (Nakase et al., 2020; Shimozaki et al., 2018; Steffen et al., 2016; Uhorchak et al., 2003).

Table 1. Summary of prospective studies investigating muscle strength and knee and anterior cruciate ligament injury risk

Study	No. of participants	Sex	Age	Sport or activity	Strength measurement	Follow-up	Outcome	Finding
Ekstrand and Gillquist (1983)	180	M	17-38, 24.6 ± 4.6	Soccer	Maximal isokinetic concentric hamstrings and quadriceps (30 and 180 °/s).	1 yr	Acute noncontact knee injury	Lower quadriceps strength ↑
Söderman et al. (2001)	146	F	20.6 ± 4.7	Soccer	Maximal isokinetic concentric and eccentric hamstrings and quadriceps (90 °/s).	6 mo	ACL	Lower HQ ratio at concentric action ↑
Uhorchak et al. (2003)	859	M + F	17-23	Military cadet training	Maximal isokinetic concentric and eccentric hamstrings and quadriceps (60 °/s).	4 yr	Noncontact ACL	NA
Myer et al. (2009)	22 (+ 110 controls)	F	High-school and collegiate	Soccer and basketball	Maximal isokinetic concentric hamstrings and quadriceps (300 °/s).	5 yr	ACL	Lower HQ ratio ↑
Nilstad, et al. (2014)	173	F	25.1 ± 4.1	Soccer	Maximal isokinetic concentric hamstrings and quadriceps (60 °/s). Maximal isometric hip abduction and 1RM leg press.	7 mo	Knee injury	NA
Steffen et al. (2016)	867	F	20.9 ± 4.0	Handball and soccer	Maximal isokinetic concentric hamstrings and quadriceps (60 °/s). Maximal isometric hip abduction and 1RM leg press.	8 yr	Noncontact ACL	NA
Vacek et al. (2016)	109 (+ 227 controls)	M + F	14-23	Lacrosse, basketball, soccer, American football, field hockey, rugby and volleyball	Knee and ankle flexion and extension (detailed information not described). Maximal isometric hip flexion, extension, abduction and adduction. Isometric trunk flexion and extension.	Over 4 yr	Noncontact ACL	NA

Khayambashi et al. (2016)	501	M + F	Males: 21.5 ± 5.5 Females: 20.9 ± 4.2	Futsal, soccer, basketball, handball and volleyball	Maximal isometric hip external rotation and abduction.	1 yr	Noncontact ACL	Lower hip external rotation and abduction strength ↑
Bakken et al. (2018)	369	M	26.0 ± 4.7	Soccer	Maximal isokinetic concentric hamstrings and quadriceps (60 and 300 °/s). Maximal isokinetic eccentric hamstrings (60 °/s). Maximal eccentric hip abduction and adduction. Maximal isometric bilateral adductor squeeze (45°).	2 yr	Acute knee injury	NA
Shimozaki et al. (2018)	180	F	High-school	Basketball	Maximal isokinetic hamstrings and quadriceps (60 °/s). Maximal isometric hip abduction.	3 yr	Noncontact ACL	Greater hip abduction strength ↑
Nakase et al. (2020)	317	F	High-school	Basketball and handball	Maximal isokinetic hamstrings and quadriceps (60 °/s). Maximal isometric hip abduction.	3 yr	Noncontact ACL	Greater hip abduction strength ↑

M, Male; F, Female; ACL, anterior cruciate ligament; HQ, hamstrings to quadriceps; 1RM, one-repetition maximum; ↑ indicates increased risk; NA indicates no significant association

2.5.3 Previous knee injury

A history of acute knee (Arnason et al., 2004; Hägglund et al., 2006) and ACL injuries (Walden et al., 2006) has been found to increase the risk of subsequent acute knee injury by two- to five-fold in adult male soccer athletes. Meeuwisse et al. (2003) also found that previous knee injury increased the risk of new knee injury by four-fold in male collegiate basketball athletes. In contrast, Engebretsen et al. (2011) studied adult male soccer athletes but did not report any association between previous knee injury and new acute knee injury. In addition, no association between previous and new knee sprains (Faude et al., 2006), as well as previous and new knee injuries (Nilstad et al., 2014), was reported in adult female soccer athletes.

Three studies in youth female soccer athletes found a two- to six-fold increase in the risk of sustaining new knee injury in athletes with a history of previous knee injury (Clausen et al., 2016; Kucera et al., 2005; Steffen et al., 2008). In contrast, Hägglund and Walden (2016) reported no association between previous and new acute knee injuries in female youth soccer athletes.

A history of previous ACL injury has been found to be a strong risk factor for new ACL injury in both male and female athletes in several studies (Brumitt et al., 2019; Faude et al., 2006; Orchard et al., 2001; Paterno et al., 2012; Paterno et al., 2014). Follow-up studies have shown that 9%–12% of patients sustain a new ACL injury in the ipsi- or contralateral knee during the 5 years and 23% during the 15 years after ACL revision surgery (Bourke et al., 2012; Salmon et al., 2005; Shelbourne et al., 2009). A recent meta-analysis revealed that a younger age and return to high-level sports are risk factors for second ACL injury (Wiggins et al., 2016). A history of ACL injury has also been associated with increased risk of hamstring injury (Toohey et al., 2017).

2.5.4 Knee function

There are several patient-reported measures for knee function available for use in research and clinical practice (Tanner et al., 2007). The KOOS questionnaire was developed in 1998 to assess short- and long-term patient-relevant outcomes following knee injury (Roos et al., 1998). The KOOS is one of the most widely used questionnaires for the evaluation of symptoms and functional limitations after knee injury (Collins et al., 2011; Tanner et al., 2007). Normative KOOS subscale scores for previously knee-healthy youth athletes have also been reported (Cameron et al., 2013).

To date, three studies have investigated the association between KOOS subscale scores and knee injury risk (Clausen et al., 2016; Engebretsen et al., 2011; Steffen et al., 2008). Lower scores in all KOOS subscales (Steffen et al., 2008) and, particularly, in the Activities of Daily Living (ADL), Sport and Recreation (Sport/Rec) and Knee-Related Quality of Life (QOL) subscales (Clausen et al., 2014) have been associated with increased risk of knee injury in youth female soccer athletes. In contrast, Engebretsen et al. (2011) reported no association between any KOOS subscale score and knee injury in adult male soccer athletes.

2.5.5 External risk factors

The highest knee injury rates among team sports in US high school athletes have been reported to be in American football, soccer, basketball and lacrosse, whereas injury risk seems to be relatively low in volleyball, baseball and softball (Ingram et al., 2008; Swenson et al., 2013). Correspondingly, the highest risk for ACL injury in male athletes seems to be in American football, lacrosse and soccer in male athletes and soccer, basketball and lacrosse in female athletes (Gornitzky et al., 2016; Swenson et al., 2013). The increased risk of sustaining knee (Ingram et al., 2008; Swenson et al., 2013) and ACL (Arendt et al., 1999; Walden et al., 2011a) injuries during games compared to practices is well documented. Weather conditions in male Australian football (Orchard et al., 2001) and shoe type in male American football (Lambson et al., 1996) athletes have also been suggested as risk factors for ACL injury. In addition, Olsen et al. (2003) reported that the playing surface might affect the risk of ACL injury in female handball athletes.

2.6 Risk factors for ankle injury

2.6.1 Internal risk factors

Three different outcomes typically exist in ankle injury risk factor studies: ankle injury, ankle sprain or lateral/inversion ankle sprain. The lateral ligament complex consists of the anterior talofibular, calcaneofibular and posterior talofibular ligaments (van den Bekerom et al., 2008). There is evidence that a younger age could be a risk factor for ankle injury (Nilstad et al., 2014) and ankle sprain (Doherty et al., 2014), but in contrast to ACL injury, the female sex has not been reported to be a risk factor for lateral ankle sprain (Beynnon et al., 2005; Roos et al., 2017). As in the case of ACL injury, previous ankle injury has been found to be a strong risk factor for new ankle injury (Engebretsen et al., 2010; McKay et al., 2001), ankle sprain (de Noronha et al., 2013; Kofotolis et al., 2007) and lateral ankle sprain (Hiller et al., 2008; Tyler et al., 2006). A higher body mass index has also been associated with increased risk of lateral ankle sprain in male athletes (Eagle et al., 2019; Fousekis et al., 2012; Gribble et al., 2016; Tyler et al., 2006).

Other internal risk factors that have been associated with increased risk of acute ankle injury are impairments in postural balance (Attenborough et al., 2017; Gribble et al., 2016; Trojian & McKeag, 2006; Wang, et al., 2006), diminished joint deficits in ankle joint proprioception (Payne et al., 1997; Willems et al., 2005b) and lower dorsiflexion (Hadžić et al., 2009; Willems et al., 2005a), higher calcaneal eversion (Beynnon et al., 2001) and higher first metatarsophalangeal (Willems et al., 2005b) range of motion. In addition, a slower reaction time in tibialis anterior and gastrocnemius muscles to a sudden inversion perturbation in male athletes (Willems et al., 2005a) and a lower knee valgus angle in drop jump in female athletes (Nilstad et al., 2014) have been suggested to increase the risk of acute ankle injury.

2.6.2 Muscle strength

Like knee injuries, noncontact acute ankle injuries in sport typically occur during landings, twistings and turnings, as well as during running (Cloke et al., 2009; Kofotolis & Kellis, 2007; McKay et al., 2001; Woods et al., 2003). Video analyses of lateral ankle sprains have revealed that an injury is a combination of ankle inversion, external rotation and perhaps dorsiflexion (Fong et al., 2009; Fong et al., 2012; Kristianslund et al., 2011; Skazalski et al., 2018). Therefore, several prospective studies have investigated ankle inversion, eversion, plantar flexion and dorsiflexion strength, as well as strength ratios between these, as risk factors for ankle injury (Table 2). However, based on kinetic chain theories, impairments of proximal core and hip muscle function have also been suggested to increase the likelihood of uncontrolled joint displacements distally and the occurrence of distal LE injury (Chuter & Janse de Jonge, 2012; Verrelst et al., 2018; Wilkerson et al., 2012).

Three prospective studies have investigated the association between hip strength and ankle injury (Table 2). Lower hip extension and abductor strength have been associated with increased risk of ankle sprain (De Ridder et al., 2017; Powers et al., 2017), but such associations were not found in two other studies (McHugh et al., 2006; Nilstad et al., 2014). In addition, in the retrospective study of Iguchi et al. (2016), no association between 1RM back squat strength and ankle sprain was reported in Japanese male American football athletes.

Table 2. Summary of prospective studies investigating muscle strength and ankle injury risk

Study	No. of participants	Sex	Age	Sport or activity	Strength measurement	Follow-up	Outcome	Finding
Baumhauer et al. (1995)	145	M + F	18-23	Lacrosse, soccer and field hockey	Maximal isokinetic ankle dorsifexion, plantar flexion, inversion and eversion (30 °/s).	1 yr	Inversion ankle sprain	Greater eversion to inversion ratio ↑
Payne et al. (1997)	42	M + F	18-22	Basketball	Maximal isokinetic concentric and eccentric ankle dorsiflexion, plantar flexion, inversion and eversion (30 and 180 °/s).	9 wk	Ankle injury	NA
Beynnon et al. (2001)	118	M + F	18-23	Lacrosse, soccer and field hockey	Maximal isokinetic concentric and eccentric ankle dorsiflexion, plantar flexion, inversion and eversion (30 °/s).	1 season	Inversion ankle sprain	NA
Willems et al. (2005a)	241	M	17-28, 18.3 ± 1.1	Physical education students training	Maximal isokinetic concentric ankle dorsiflexion and plantar flexion (30 and 180 °/s). Maximal isokinetic concentric and eccentric ankle inversion and eversion (30 and 180 °/s).	3 yr	Lateral ankle sprain	Lower ankle dorsiflexion strength (30 °/s) ↑

Willems et al. (2005b)	159	F	17-26, 18.3 ± 1.1	Physical education students training	Maximal isokinetic concentric ankle dorsiflexion and plantar flexion (30 and 180 °/s). Maximal isokinetic concentric and eccentric ankle inversion and eversion (30 and 180 °/s).	3 yr	Lateral ankle sprain	NA
Wang et al. (2006)	42	M	16.5 ± 1.1	Basketball	Maximal isokinetic concentric and eccentric ankle inversion and eversion (60 and 180 °/s).	1 season	Ankle injury	NA
McHugh et al. (2006)	169	M + F	14-18, 16 ± 1	American football, basketball, soccer and gymnastics	Maximal isometric hip flexion, abduction and adduction.	2 yr	Noncontact lateral ankle sprain	NA
Hadžić et al. (2009)	38	M	15-34, 21 ± 5	Volleyball	Maximal isokinetic concentric ankle dorsiflexion and plantar flexion (60 °/s).	6 mo	Ankle sprain	Greater ankle plantar flexion strength (60 °/s) ↑
Fousekis et al. (2012)	100	M	23.6 ± 4.2	Soccer	Maximal isokinetic concentric and eccentric ankle dorsiflexion and plantar flexion (60 °/s).	10 mo	Noncontact lateral ankle sprain	Greater difference between legs in eccentric ankle plantar flexion strength ↑
Nilstad et al. (2014)	173	F	25.1 ± 4.1	Soccer	Maximal isokinetic concentric hamstrings and quadriceps (60 °/s). Maximal isometric hip abduction and 1RM leg press.	7 mo	Ankle injury	NA

De Ridder et al. (2017)	133	M	10-16, 12.7 ± 2.1	Soccer	Maximal isometric hip flexion, extension, abduction, adduction, internal and external rotation.	3 seasons	Lateral ankle sprain	Lower hip extension strength ↑
Powers et al. (2017)	210	M	14-34	Soccer	Maximal isometric hip abduction.	30 wk	Noncontact lateral ankle sprain	Lower hip abduction strength ↑
Eagle et al. (2019)	140	M	21-49	Military operators training	Isometric ankle inversion and eversion.	Over 1 yr	Ankle injury	NA

M, Male; F, Female; 1RM, one-repetition maximum; ↑ indicates increased risk; NA indicates no significant association

2.6.3 External risk factors

The incidence of acute ankle injury is high in indoor and court team sports (Doherty et al., 2014; Fong et al., 2007). Roos et al. (2017) reported that among collegiate team sports, the incidence of lateral ankle sprain is highest in basketball in both male and female athletes. Several studies have shown a higher risk for acute ankle injury during games compared to practices, regardless of sport or sex (Kofotolis & Kellis, 2007; Roos et al., 2017; Woods et al., 2003).

Some studies have suggested that shoe type affects the incidence of ankle injury in basketball (Garrick & Requa, 1973; McKay et al., 2001) and American football (Cameron & Davis, 1973; Torg & Quedenfeld, 1971) athletes. Ankle taping has also been reported to reduce the risk of ankle injury in basketball athletes (Garrick & Requa, 1973; Moiler et al., 2006). Furthermore, many studies have shown that the use of an ankle brace can prevent ankle injury, especially in athletes with previous ankle injury (McGuine et al., 2011; McGuine et al., 2012; Sitler et al., 1994; Surve et al., 1994).

3 AIMS OF THE STUDY

The aims of this thesis were the following:

1. To describe the incidence and characteristics of floorball injuries in youth athletes (Study I).

2. To investigate LE muscle strength variables as potential risk factors for any type of acute and noncontact acute knee and ACL injuries in youth basketball and floorball athletes. The hypothesis was that lower muscle strength increases the risk of these injuries (Study II).

3. To investigate LE muscle strength variables as potential risk factors for any type of acute and noncontact acute ankle injury in youth basketball and floorball athletes. The hypothesis was that lower muscle strength increases the risk of these injuries (Study III).

4. To investigate previous acute knee injury and knee function as potential risk factors for any type of acute and noncontact acute knee injury in youth basketball and floorball athletes. The hypothesis was that previous acute knee injury and lower knee function increase the risk of these injuries (Study IV).

4 MATERIALS AND METHODS

4.1 Study design and participants

All studies of this thesis contain data from the predictors of LE injuries in team sports (PROFITS) study (Pasanen et al., 2015). The PROFITS study is a 4.5-year prospective cohort study aiming to investigate anatomical, biomechanical, neuromuscular, genetic and demographic risk factors for injuries in youth team-sports athletes. The data used in the thesis were collected from the first data collection period (from May 2011 to April 2014).

Participants were recruited from nine basketball and nine floorball teams from six sports clubs in Tampere city district. All teams played at the two highest junior or adult league levels. Athletes who were junior-aged (≤21 years) and official team members entered the study during the preseason (April–May) in 2011, 2012 or 2013. Altogether, 214 male (102 basketball and 112 floorball) and 189 female (107 basketball and 82 floorball) athletes participated. Athletes signed written informed consent before entering the study (including parental consent for athletes under 18 years).

During the preseasons, athletes completed a baseline test battery (Pasanen et al., 2015), including a baseline questionnaire and physical tests at the UKK institute, Tampere, Finland. The baseline questionnaire includes questions on knee injury history and function (Study IV). Muscle strength tests (Studies II and III) were part of the physical tests. After the baseline test battery, injury and exposure registration continued until the end of the season (April 2012, 2013 and 2014). A total of 211 male and 185 female athletes participated in injury and exposure registration (Figure 4). The characteristics of the athletes in the individual studies are presented in Table 3. The inclusion criteria of athletes in the individual studies were as follows: floorball athletes who played in junior series in Study I, athletes who participated in all four muscle strength tests in Studies II and III and athletes who completed the questions on knee injury history and function in Study IV.

Figure 4. The flow of athletes

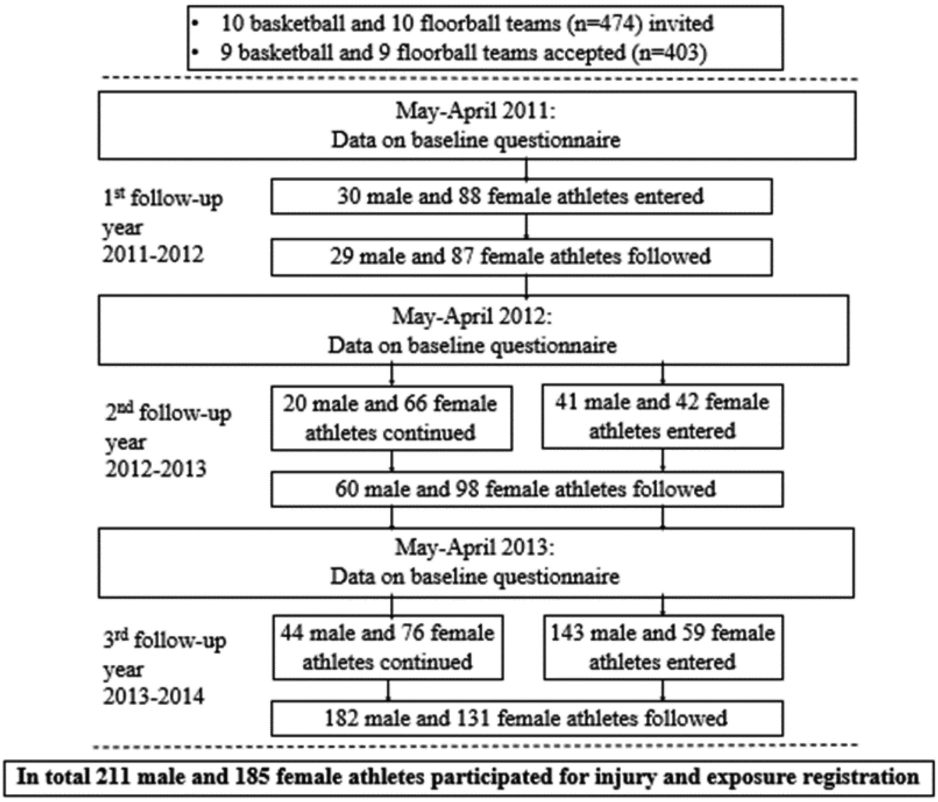


Table 3. Characteristics of participants

	Study I		Study II & III		Study IV	
	Male	Female	Male	Female	Male	Female
Basketball (n)	-	-	93	96	100	103
Floorball (n)	111	75	95	78	111	80
Age (years)	16.9 ± 1.3	16.1 ± 1.5	16.0 ± 1.6	15.4 ± 2.0	16.1 ± 1.7	15.5 ± 2.0
Height (cm)	177.5 (164.5–199)[a]	166.5 ± 5.6	178.6 ± 8.1	167.4 ± 6.2	179.0 ± 8.1	167.6 ± 6.3
Weight (kg)	68.3 (52.4–98.5)[a]	59.4 (45.5–80.0)[a]	69.2 ± 10.9	61.0 ± 8.6	69.6 ± 11.1	61.1 ± 8.6
BMI (kg/m²)[b]	21.7 (17.2–29.8)[a]	21.5 (17.8–27.2)[a]	21.6 ± 2.7	21.7 ± 2.7	21.7 ± 2.7	21.7 ± 2.8
Playing experience (years)	8.7 ± 2.8	6.0 ± 2.5	8.1 ± 3.1	6.3 ± 2.5	8.1 ± 3.1	6.4 ± 2.6

[a]Values are presented as median (range); [b]Body mass index

4.2 Muscle strength tests

4.2.1 Maximal one-repetition leg press strength

A seated leg press machine (Technogym®, Gambettola, Italy) was used to measure the combined maximal extension strength of the LE muscles. The distance between feet was 20 cm, and the ends of shoes were 10 cm above the lowest end of the foot plate. The back of the seat was set at a 30° angle relative to the floor. A vertical bar was placed at the point where the knees reached the target knee angle of 80°. The target knee angle was measured with a goniometer (HiRes, Baseline® Evaluation Instruments, White Plains, NY, USA). The standardized warm-up protocol consisted of three sets with gradually increasing weights (Pasanen et al., 2015). The 1RM leg press test protocol started with 80–150 kg, depending on the athlete's weight-bearing experience. At the starting point, the athlete's legs were extended, and the weights were then lowered until the knees formed the correct angle and then returned to the starting position as hard as possible (Figure 5). After each successful trial, the weights were increased by a maximum of 30 kg after the first trials and by a minimum of 10 kg after the last trials for the next attempt. The recovery period between the attempts was two minutes, and the test ended when 1RM was reached. Body mass normalized values were used in the analyses (Nilstad et al., 2014; Steffen et al., 2016). A similar test has been proven to be a reliable tool for measuring muscle strength regardless of sex (Seo et al., 2012).

Figure 5. 1RM leg press strength measurement

4.2.2 Maximal isokinetic quadriceps and hamstrings strength

Maximal concentric isokinetic quadriceps and hamstrings strength was measured in the first study year (2011) using a noncommercial dynamometer (Neuromuscular Research Center, University of Jyväskylä, Finland). In the second study year (2012), the dynamometer was replaced by the Biodex Multi-Joint System Pro dynamometer (Biodex System 4, Biodex Medical Systems, Inc., Shirley, NY, USA). The test procedure was the same irrespective of the dynamometer used. The test range of motion was 90° through 15° of knee flexion, with an angular velocity of 60°/s (Figure 6). A standardized test protocol (Pasanen et al., 2015) with gradually increasing intensity was performed, and the final test included three repetitions with maximum power. The maximal strength was reported as peak torque (newton by metre [N·m]), and a body mass normalized value was used in the analysis. The strength difference between legs, as well as the HQ strength ratio, was calculated. Isokinetic strength testing has been established as a reliable tool for assessing muscle strength (Brosky et al., 1999).

Figure 6. Maximal concentric isokinetic quadriceps and hamstrings strength measurement

To evaluate the reproducibility of the measurements between the two used dynamometers, twelve 14–15 years old male soccer athletes (24 legs) were tested with both dynamometers by different testers who collected the data. The intra-cluster correlation coefficient value (3,k) was 0.81 (95% confidence interval [CI] 0.4–30.93) and 0.79 (95% CI 0.47–0.91) for the isokinetic quadriceps and hamstrings strength measurements, respectively, indicating good test–retest reliability of the tests.

4.2.3 Maximal hip abductor strength

Maximal isometric hip abductor strength (kg) was tested with a hand-held dynamometer (Hydraulic Push-Pull Dynamometer, Baseline® Evaluation Instruments, White Plains, NY, USA). The test was performed with the athlete lying, with legs extended, in a supine position on a bench. The pelvis and the contralateral thigh were fixed with a belt, and the athlete held their arms across the chest during the test. The dynamometer was positioned approximately 2 cm proximal to the lateral malleolus, with the leg in a neutral position and the foot in slight dorsiflexion (Figure 7). The dynamometer was applied in a fixed position, and the athlete held a muscle contraction against the dynamometer for approximately two seconds (make-test). After one test trial, the athlete performed two maximal contractions with a 10-second rest between the attempts. The better result (kg) was recorded, and a body mass normalized value was used in the analysis. The strength difference between the legs was also calculated. A similar procedure has been demonstrated to have excellent intra-tester reliability, with a measurement variation of 3% (Thorborg et al., 2010), and acceptable inter-tester reliability, with a measurement variation of 22% (Thorborg et al., 2013).

Figure 7. Maximal isometric hip abductor strength measurement

4.3 Knee injury history and knee function

A previous acute knee injury was recorded if an athlete had ever sustained one or more sport-related acute knee injury according to the baseline questionnaire. Knee function was measured by the KOOS. The KOOS is a self-administered knee-specific questionnaire comprising five subscales: Pain, Symptoms, ADL, Sport/Rec and QOL. Each item is scored from 0 (no problems) to 4 (extreme problems) using a Likert scale. A normalized score from 0 to 100 is then calculated for each subscale, where 0 indicates extreme problems and 100, no problems (Roos et al., 1998). KOOS subscale scores were recorded for both knees separately (Clausen et al., 2016; Steffen et al., 2008). Missing data were handled according to the recommendations in *A User's Guide to Knee Injury and Osteoarthritis Outcome Score (KOOS).* The Finnish-translated KOOS version has demonstrated good validity and reliability (Multanen et al., 2018).

4.4 Injury and exposure registration

During a follow-up period, two study physicians contacted teams' coaches once a week to check injured athletes. After each injury reported, the injured athlete was interviewed by telephone using a structured questionnaire (Pasanen et al., 2015). The injury definition was adapted from the definition by Fuller et al. (2006). An injury was defined as any acute (resulting in a specific identifiable event) injury occurring in teams' scheduled practices or games making the injured athlete unable to fully participate in practices or games at least during the next 24 hours. An ACL injury was defined as a rupture of the ACL. All ACL ruptures were verified by MRI. In Study I, injuries that had occurred in adult league games were excluded.

In Study I, the injuries were classified as contact (i.e., direct contact with the injured body region), indirect contact (contact with other body parts) or noncontact. In Studies II–IV, knee and ankle injuries were classified as contact (i.e., direct contact with the injured knee or ankle) and noncontact (i.e., no direct contact with the injured knee or ankle). A recurrent injury was defined as an injury at the same site and of the same type as a prior injury that occurred after the athlete's full return to sport from a prior injury (Fuller et al., 2006). The severity of injury was defined using four categories: minimal (absence from sport for 1–3 days), mild (4–7 days), moderate (8–28 days) and severe (>28 days) (Fuller et al., 2006).

During the follow-up, the coach of each team recorded athletes' participation in practices and games in a team diary (Pasanen et al., 2015). The diaries were returned after each follow-up month, and the individual monthly exposure time (h) for practices and games was registered for athletes. In Studies II–IV, total exposure hours of the month, when an athlete sustained a knee or ankle injury, were estimated by dividing the days from the beginning of the month to the injury date by all days of the month and then by multiplying the result by the athlete's registered total exposure hours of that month. Injury incidences were calculated as the number of injuries per 1,000 player-hours and reported with 95% CIs: ([*Incidence rate* – 1.96 * *Standard error of incidence rate*] * 1,000 hours) to ([*Incidence rate* + 1.96 * *Standard error of incidence rate*] * 1,000 hours). Recurrent injuries were included in incidence calculations.

4.5 Statistical analysis

Descriptive data were presented as the mean ± standard deviation (SD) or the median and range. In Study I, the mid-P exact test was used to compare injury incidence rates between sexes, and Benjamini–Hochberg adjustments for P values were calculated to control the false discovery rate. An independent-samples t test or the Mann–Whitney U test for continuous variables and Fisher's exact test for categorical variables were used to compare basketball and floorball athletes in Studies II–IV, as well as injured and uninjured athletes or legs in Studies II and III. In Study IV, mean differences for the KOOS subscale scores between injured and uninjured legs were analyzed according to the mixed linear models (gamma distribution). To correct potential dependence between the right and left knees, an athlete was considered a cluster with two knees. In addition, Pearson's and Spearman's correlation coefficients were used to evaluate linear correlation between the athletes' ages and risk factors in Studies II and III. P values less than 0.05 were considered significant. In Study I, the critical value for a false discovery rate was set to 0.25.

In Studies II–IV, unadjusted and adjusted Cox mixed-effect regression models were calculated for risk factors using the athlete or the leg as a unit of analysis, depending on the risk factor. In all models, the sport club was considered as a cluster. In the models using the leg as a unit of analysis, the athlete was also considered as a cluster (with two legs). The adjustment factors that might mostly influence the risk of injury were included in the adjusted models according to the number of injuries in each risk model, following the recommendation of 10 injuries needed per included variable (Peduzzi et al., 1995). A receiver operating characteristics (ROC) curve analysis was calculated to assess the combined sensitivity and specificity of a risk factor in cases where significant associations between the risk factor and the outcome were found. The combined sensitivity and specificity was defined as "excellent" (0.90–1.00), "good" (0.80–0.89), "fair" (0.70–0.79), "poor" (0.60–0.69) and "fail" (0.50–0.59) (Safari et al., 2016).

Statistical analyses were conducted using SPSS for Windows (v 22.0.0, SPSS Inc., Chigaco, Illinois, USA) and OpenEpi (v 3.01)—except for the regression models, which were conducted in R (v3.1.2; R Foundation for Statistical Computing, Vienna, Austria).

5 RESULTS

5.1 Acute injuries in youth floorball athletes (Study I)

5.1.1 Injury characteristics

A total of 144 (58 in male and 86 in female athletes) acute injuries occurred during the study period, with injury incidence of 2.1 (95% CI 1.7–2.4) injuries per 1,000 player-hours (Table 4). Of these injuries, 59 occurred during games and 85 in practices. Injury incidence during games and practices was 26.9 (95% CI 20.1–33.6) and 1.3 (95% CI 1.0–1.5) per 1,000 player-hours, respectively.

The ankle was the most common site of injury (37%), followed by the knee (18%) and thigh (14%). There were 78 joint or ligament injuries (54% of injuries) and 31 muscle or tendon strains (22% of injuries). The numbers of ankle and knee joint/ligament injuries were 52 and 21, respectively. Of these, 49 were lateral ankle sprains and 8 were ACL injuries. All ACL injuries occurred in female athletes. Most muscle or tendon strains affected the posterior thigh (n = 9), anterior thigh (n = 8) and groin (n = 7).

As shown in Table 5, 37 (25.7%) injuries were classified as severe, and 32 of these affected the LEs. The most typical severe injuries involved the knee (n = 15) and ankle (n = 10), and the most common type of severe injuries were joint/ligament injuries (n = 25) and muscle/tendon strains (n = 5). The most common injury situation was direction change/stop (21% of injuries), followed by collision/body contact with another athlete (19% of injuries). Proportions of contact, indirect contact and noncontact injuries were 32%, 12% and 56%, respectively. Eighty-six percent of knee ligament injuries, 77% of ankle ligament injuries and all ACL injuries occurred in noncontact or indirect contact mechanisms. Twenty-four injuries (17%) were recurrent injuries. Of these, 20 were lateral ankle sprains.

Table 4. Number and incidence of acute time-loss injuries for female and male floorball in junior league games

	All (n = 186)		Female (n = 75)		Male (n = 111)	
	n[a]	Incidence (95% CI)	n[a]	Incidence (95% CI)	n[a]	Incidence (95% CI)
All injuries[b]	144	2.06 (1.72-2.39)	86	2.40 (1.89-2.91)	58	1.70 (1.26-2.14)
Game-related injuries[c]	59	26.87 (20.10-33.63)	35	36.46 (24.60-48.31)	24	19.42 (11.72-27.11)
Training-related injuries[d]	85	1.25 (0.99-1.52)	51	1.46 (1.06-1.86)	34	1.03 (0.69-1.38)
Injury location[b]						
Ankle	53	0.76 (0.55-0.96)	32	0.89 (0.58-1.20)	21	0.62 (0.35-0.88)
Knee	26	0.37 (0.23-0.51)	16	0.45 (0.23-0.66)	10	0.29 (0.11-0.48)
Thigh	20	0.29 (0.16-0.41)	13	0.36 (0.17-0.56)	7	0.21 (0.05-0.36)
Lower back/sacrum	8	0.11 (0.04-0.19)	6	0.17 (0.03-0.30)	2	0.06 (0.00-0.14)
Hip/groin	8	0.11 (0.04-0.19)	5	0.14 (0.02-0.26)	3	0.09 (0.00-0.19)
Wrist	6	0.09 (0.02-0.15)	4	0.11 (0.00-0.22)	2	0.06 (0.00-0.14)
Head/face	5	0.07 (0.01-0.13)	3	0.08 (0.00-0.18)	2	0.06 (0.00-0.14)
Foot/toe	5	0.07 (0.01-0.13)	1	0.03 (0.00-0.18)	4	0.12 (0.00-0.23)
Lower leg/achilles	4	0.06 (0.00-0.11)	1	0.03 (0.00-0.18)	3	0.09 (0.00-0.19)
Shoulder	4	0.06 (0.00-0.11)	2	0.06 (0.00-0.13)	2	0.06 (0.00-0.14)
Neck/upper back	2	0.03 (0.00-0.07)	2	0.06 (0.00-0.13)	-	NA
Abdomen/rib	2	0.03 (0.00-0.07)	1	0.03 (0.00-0.08)	1	0.03 (0.00-0.09)
Finger	1	0.01 (0.00-0.04)	-	NA	1	0.03 (0.00-0.09)
Injury type[b]						
Joint/ligament	78	1.12 (0.87-1.36)	50	1.39 (1.01-1.78)	28	0.82 (0.52-1.13)
Muscle/tendon	31	0.44 (0.29-0.69)	19	0.53 (0.29-0.77)	12	0.35 (0.15-0.55)
Contusion	13	0.19 (0.08-0.29)	6	0.17 (0.03-0.30)	7	0.21 (0.05-0.36)
Fracture/bone injury	9	0.13 (0.04-0.21)	2	0.06 (0.00-0.13)	7	0.21 (0.05-0.36)
Undefined[e]	8	0.11 (0.04-0.19)	6	0.17 (0.03-0.30)	2	0.06 (0.00-0.14)
Concussion	3	0.04 (0.00-0.09)	3	0.08 (0.00-0.18)	-	NA
Eye injury	2	0.03 (0.00-0.07)	-	NA	2	0.06 (0.00-0.14)
Specific injuries[b]						
ACL rupture[f]	8	0.11 (0.04-0.19)	8	0.22 (0.07-0.38)	-	NA
Lateral ankle sprain	49	0.70 (0.50-0.90)	30	0.84 (0.54-1.14)	19	0.56 (0.31-0.81)

[a]Number of injuries in junior league games and team practises; [b]Incidence is based on 1000 hours of total exposure (junior game + practice hours); [c]Incidence is based on 1000 hours of junior game exposure; [d]Incidence is based on 1000 hours of training exposure; [e]Undefined back and neck injuries with unspecified diagnosis; [f]Anterior cruciate ligament rupture of the knee; NA = not available

Table 5. Severity of floorball injuries by body region, given as number of injuries

Body region	Mimimal/moderate (1-7 days)			Moderate (8-28 days)			Severe (> 28 days)			All injuries		
	Female	Male	All	Female	Male	All	Female	Male	All	Female	Male	All
Head/neck	2	-	2	2	-	2	-	2	2	4	2	6
Upper limbs	3	2	5	2	2	4	1	1	2	6	5	11
Spine/trunk	5	1	6	2	2	4	1	-	1	8	3	11
Lower limbs	30	25	55	18	11	29	20	12	32	68	48	116
All injuries	40	28	68	24	15	39	22	15	37	86	58	144

5.1.2 Group differences

The overall injury incidence was over 20-fold higher during games compared to practices (incidence rate ratio [IRR] 21.2, 95% CI 15.3–29.8). Female athletes had significantly higher game injury (IRR 1.9, 95% CI 1.1–3.2) and joint/ligament injury rates (IRR 1.7, 95% CI 1.1–2.7) compared to male athletes (Table 6).

Table 6. Incidence rate ratio for female versus male athletes for games and practices as well as for injury locations and types

	IRR (95% CI)[a]	p Value	p Value[BH]
All injuries	1.41 (1.01-1.98)	0.04	0.25
Game-related injuries	1.88 (1.12-3.19)	0.02	0.17[††]
Training-related injuries	1.41 (0.92-2.20)	0.12	0.42
Injury location			
Ankle	1.45 (0.84-2.55)	0.19	0.42
Knee	1.52 (0.69-3.48)	0.30	0.44
Thigh	1.77 (0.71-4.72)	0.23	0.42
Lower back/sacrum	2.85 (0.60-20.54)	0.20	0.42
Hip/groin	1.59 (0.37-8.06)	0.55	0.65
Wrist	1.90 (0.34-14.85)	0.49	0.61
Head/face	1.43 (0.21-12.00)	0.73	0.79
Foot/toe	0.24 (0.01-1.89)	0.20	0.42
Lower leg/achilles	0.32 (0.01-2.97)	0.35	0.49
Shoulder	0.95 (0.10-9.14)	0.96	0.97
Neck/upper back	NA)	0.26	0.42
Abdomen/rib	0.95 (0.02-37.09)	0.97	0.97
Finger	NA	0.49	0.61
Injury type			
Joint/ligament	1.70 (1.07-2.73)	0.02	0.17[††]
Muscle/tendon	1.51 (0.73-3.20)	0.27	0.42
Contusion	0.82 (0.26-2.52)	0.72	0.79
Fracture/bone injury	0.27 (0.04-1.22)	0.09	0.42
Undefined[b]	2.85 (0.60-20.54)	0.20	0.42
Concussion	NA	0.13	0.42
Eye injury	NA	0.24	0.42
Specific injuries			
ACL rupture[c]	NA	0.01	0.17[††]
Lateral ankle sprain	1.50 (0.85-2.71)	0.17	0.42

[a]Incidence rate ratio for female versus male athletes. Significance level was < 0.05. NA = not available; [b]Undefined back and neck injuries with unspecified diagnosis; [c]Anterior cruciate ligament rupture of the knee; [BH]Benjamini-Hochberg adjusted p-values for controlling Falce Discovery Rate of of 0.25; [↑↑]Significant Benjamini-Hohcberg adjusted p values

5.2 Muscle strength and knee and ACL injury (Study II)

5.2.1 Injury characteristics in males

A total of 17 (8 in basketball and 9 in floorball athletes) new acute knee injuries occurred, and 9 of these were noncontact injuries. In addition, two athletes had reinjured the same knee once. There were five bone bruises, five joint or ligament sprains, three meniscal lesions, one ACL injury (noncontact), one patellar dislocation, one intra-articular fracture and one unspecified acute knee injury. The incidence rates for any type of acute and noncontact acute knee injury were 0.3 (95% CI 0.2–0.4) and 0.2 (95% CI 0.1–0.3) injuries per 1,000 player-hours, respectively. The incidence rates for any type of acute knee injury in basketball and floorball athletes were 0.1 (95% CI 0.05–0.2) and 0.2 (95% CI 0.1–0.3) injuries per 1,000 player-hours, respectively.

5.2.2 Injury characteristics in females

There were 34 (11 in basketball and 23 in floorball athletes) new acute knee injuries in 29 athletes (five athletes had both knees injured), and 27 occurred in noncontact situations. Three athletes had reinjured the same knee once. There were 16 ACL injuries, and 15 of these were noncontact injuries. In addition, seven bone bruises, five joint or ligament sprains, one meniscal lesion and five unspecified acute knee injuries were diagnosed. The incidence rates for any type of acute and noncontact acute knee injury were 0.6 (95% CI 0.4–0.8) and 0.5 (95% CI 0.3–0.6) injuries per 1,000 player-hours, respectively. The incidence rate for any type of acute ACL injury was 0.3 (95% CI 0.1–0.4) injuries per 1,000 player-hours. The incidence rates for any type of acute knee injury in basketball and floorball athletes were 0.3 (95% CI 0.1–0.4) and 0.3 (95% CI 0.2–0.4) injuries per 1,000 player-hours, respectively.

5.2.3 Risk factor analyses for male injuries

In the adjusted risk factor analyses, a 1 SD decrease in maximal hip abduction strength increased the risk of any type of acute injury in the same knee by 80% (hazard ratio [HR] 1.8, 95% CI 1.0–3.2, P = 0.04; Table 7). However, ROC curve analysis for hip abduction strength showed an area under the curve (AUC) of 0.66, indicating "poor" combined sensitivity and specificity of the risk factor. In the unadjusted analyses, a 1 SD increase in 1RM leg press strength and difference between legs in isokinetic quadriceps strength were associated with a 2.3-fold increase in the risk of noncontact acute knee injury (HR 2.3, 95% CI 1.1–4.7, P = 0.02, and 1.9, 95% CI 1.0–3.4, P = 0.04, respectively; Table 7). Adjusted analyses for noncontact knee injuries and any risk factor analyses for ACL injuries were not performed for males due to the low number of these injuries.

Table 7. Unadjusted and adjusted hazard ratios (per one standard deviation increase), with 95% confidence intervals for strength variables for any type of acute and noncontact acute knee injury in male athletes[a]

	Any type		Noncontact
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)
Athlete as a unit of analysis			
Leg press (kg/kg)[b]	1.52 (0.92-2.49)	1.42 (0.79-2.54)[d]	**2.30 (1.14-4.65)**
Quadriceps between-leg differences (N·m)[c]	1.35 (0.85-2.15)	1.13 (0.72-1.77)[d]	**1.85 (1.02-3.35)**
Hamstrings between-leg difference (N·m)[c]	1.15 (0.75-1.76)	1.14 (0.69-1.86)[d]	1.13 (0.63-2.03)
Hip abduction between-leg differences (kg)[c]	1.25 (0.81-1.93)	1.04 (0.69-1.57)[d]	1.06 (0.58-1.93)
Leg as a unit of analysis			
Quadriceps (N·m/kg)[b]	1.51 (0.92-2.49)	1.50 (0.88-2.57)[d]	2.00 (0.96-4.15)
Hamstrings (N·m/kg)[b]	1.20 (0.72-2.01)	1.04 (0.63-1.72)[d]	1.41 (0.68-2.90)
HQ ratio (%)	0.80 (0.49-1.33)	0.72 (0.42-1.24)[d]	0.68 (0.31-1.46)
Hip abduction (kg/kg)[b]	0.56 (0.31-1.01)	**0.56 (0.32-0.97)**[d]	0.65 (0.29-1.47)

[a]Values in parentheses are 95% CIs and significant results are marked in bold; [b]Body mass normalized values; [c]Difference between stronger and weaker leg; [d]Adjustment factor: previous acute knee injury

5.2.4 Risk factor analyses for female injuries

In the adjusted risk factor analyses, none of the muscle strength risk factors were associated with any type of acute or noncontact acute knee or ACL injury (Tables 8 and 9). In the unadjusted analyses, greater 1RM leg press strength was associated with increased risk of noncontact acute knee injury (HR for 1 SD increase = 1.5, 95% CI 1.0–2.2, P = 0.03). The trend was similar in the adjusted analysis, but the observed difference was not statistically significant (HR for 1 SD increase = 1.5, 95% CI 1.0–2.3, P = 0.07).

Table 8. Unadjusted and adjusted hazard ratios (per one standard deviation increase), with 95% confidence intervals for strength variables for any type of acute and noncontact acute knee injury in female athletes[a]

	Any type		Noncontact	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Athlete as a unit of analysis				
Leg press (kg/kg)[b]	1.35 (0.96-1.90)	1.23 (0.83-1.84)[d]	**1.52 (1.04-2.21)**	1.48 (0.97-2.26)[d]
Quadriceps between-leg differences (N･m)[c]	0.72 (0.44-1.17)	0.74 (0.46-1.19)[d]	0.58 (0.33-1.04)	0.58 (0.34-1.01)[d]
Hamstrings between-leg difference (N･m)[c]	1.03 (0.72-1.48)	1.03 (0.69-1.53)[d]	0,98 (0.65-1.46)	0.95 (0.61-1.47)[d]
Hip abduction between-leg differences (kg)[c]	1.02 (0.70-1.48)	1.08 (0.74-1.57)[d]	1.11 (0.76-1.61)	1.20 (0.82-1.76)[d]
Leg as a unit of analysis				
Quadriceps (N･m/kg)[b]	0.96 (0.68-1.35)	0.92 (0.63-1.33)[d]	1.01 (0.69-1.48)	0.99 (0.66-1.49)[d]
Hamstrings (N･m/kg)[b]	0.78 (0.54-1.13)	0.73 (0.49-1.09)[d]	0.87 (0.58-1.31)	0.83 (0.53-1.31)[d]
HQ ratio (%)	0.75 (0.53-1.07)	0.76 (0.53-1.09)[d]	0.82 (0.55-1.22)	0.81 (0.54-1.22)[d]
Hip abduction (kg/kg)[b]	1.01 (0.72-1.44)	1.04 (0.74-1.46)[d]	0.98 (0.66-1.46)	1.00 (0.68-1.48)[d]

[a]Values in parentheses are 95% CIs CIs and significant results are marked in bold; [b]Body mass normalized values; [c]Difference between stronger and weaker leg; [d]Adjustment factors: previous acute knee injury and age

Table 9. Unadjusted and adjusted hazard ratios (per one standard deviation increase), with 95% confidence intervals for strength variables for any type of acute and noncontact acute anterior cruciate ligament injury in female athletes[a]

	Any type		Noncontact	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Athlete as a unit of analysis				
Leg press (kg/kg)[b]	1.57 (0.90-2.71)	1.51 (0.84-2.73)[d]	1.51 (0.86-2.65)	1.44 (0.78-2.64)[d]
Quadriceps between-leg differences (N･m)[c]	0.79 (0.42-1.47)	0.79 (0.44-1.40)[d]	0.75 (0.38-1.46)	0.75 (0.40-1.39)[d]
Hamstrings between-leg difference (N･m)[c]	1.34 (0.84-2.15)	1.35 (0.82-2.22)[d]	1.25 (0.76-2.04)	1.25 (0.74-2.12)[d]
Hip abduction between-leg differences (kg)[c]	1.27 (0.86-1.87)	1.35 (0.91-1.99)[d]	1.27 (0.85-1.91)	1.36 (0.90-2.06)[d]
Leg as a unit of analysis				
Quadriceps (N･m/kg)[b]	1.06 (0.64-1.76)	1.11 (0.66-1.87)[d]	1.00 (0.59-1.69)	1.05 (0.61-1.80)[d]
Hamstrings (N･m/kg)[b]	0.94 (0.56-1.57)	0.99 (0.59-1.66)[d]	0.98 (0.58-1.66)	1.03 (0.60-1.76)[d]
HQ ratio (%)	0.89 (0.53-1.48)	0.90 (0.54-1.51)[d]	0.99 (0.57-1.70)	1.01 (0.59-1.74)[d]
Hip abduction (kg/kg)[b]	0.92 (0.56-1.54)	0.96 (0.58-1.61)[d]	0.88 (0.52-1.50)	0.92 (0.54-1.57)[d]

[a]Values in parentheses are 95% CIs and significant results are marked in bold; [b]Body mass normalized values; [c]Difference between stronger and weaker leg; [d]Adjustment factor: previous acute knee injury

5.3 Muscle strength and ankle injury (Study III)

5.3.1 Injury characteristics in males

A total of 43 (26 in basketball and 17 in floorball athletes) new acute ankle injuries occurred in 38 athletes, and 24 of these were noncontact injuries. In addition, 12 athletes had reinjured the same ankle one or more times. Forty-one (95%) of all acute ankle injuries were diagnosed as lateral ankle sprains. The incidence rates for any type of acute and noncontact acute ankle injury were 0.9 (95% CI 0.7–1.1) and 0.5 (95% CI 0.3–0.7) injuries per 1,000 player-hours, respectively. The incidence rates for any type of acute ankle injury in basketball and floorball athletes were 0.6 (95% CI 0.4–0.8) and 0.3 (95% CI 0.2–0.4) injuries per 1,000 player-hours, respectively.

5.3.2 Injury characteristics in females

There were 62 (27 in basketball and 35 in floorball athletes) new acute ankle injuries in 55 athletes, and 44 occurred in noncontact situations. Twelve athletes had reinjured the same ankle one or more times. Fifty-six (90%) of all acute ankle injuries were diagnosed as lateral ankle sprains. The incidence rates for any type of acute and noncontact acute ankle injury were 1.3 (95% CI 1.0–1.6) and 0.9 (95% CI 0.7–1.1) injuries per 1,000 player-hours, respectively. The incidence rates for any type of acute ankle injury in basketball and floorball athletes were 0.7 (95% CI 0.5–1.0) and 0.6 (95% CI 0.4–0.8) injuries per 1,000 player-hours, respectively.

5.3.3 Risk factor analyses for male injuries

In the adjusted risk factor analyses, 1 SD increase in 1RM leg press strength was associated with increased risk of any type of acute ankle injury by 60 % (HR 1.6, 95% CI 1.1–2.4, P = 0.01). Greater maximal isokinetic quadriceps strength was also associated with increased risk of any type of acute ankle injury in the same knee (HR for 1 SD increase = 1.4, 95% CI 1.0–2.0, P = 0.04; Table 10). However, ROC curve analyses showed an AUC of 0.64 for 1RM leg press and 0.62 for maximal isokinetic quadriceps strength, indicating “poor” combined sensitivity and specificity of these risk factors.

Table 10. Unadjusted and adjusted hazard ratios (per one standard deviation increase), with 95% confidence intervals for strength variables for any type of acute and noncontact acute ankle injury in male athletes[a]

	Any type		Noncontact	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Athlete as a unit of analysis				
Leg press (kg/kg)[b]	**1.63 (1.17-2.27)**	**1.63 (1.12-2.39)**[e]	1.39 (0.93-2.09)	1.34 (0.89-2.01)[d]
Quadriceps between-leg difference (N·m)[c]	1.23 (0.87-1.74)	1.18 (0.83-1.67)[e]	1.44 (0.95-2.20)	1.39 (0.90-2.14)[d]
Hamstrings between-leg difference (N·m)[c]	1.10 (0.82-1.48)	1.08 (0.80-1.47)[e]	0,69 (0.41-1.16)	0.67 (0.39-1.16)[d]
Hip abduction between-leg difference (kg)[c]	1.10 (0.79-1.52)	1.02 (0.73-1.43)[e]	1.28 (0.88-1.87)	1.23 (0.85-1.79)[d]
Leg as a unit of analysis				
Quadriceps (N·m/kg)[b]	**1.50 (1.10-2.06)**	**1.43 (1.01-2.01)**[f]	1.06 (0.70-1.60)	0.99 (0.65-1.52)[d]
Hamstrings (N·m/kg)[b]	1.13 (0.83-1.53)	1.04 (0.74-1.45)[f]	0.80 (0.52-1.22)	0.74 (0.48-1.14)[d]
HQ ratio (%)	**0.71 (0.51-0.99)**	0.72 (0.52-1.00)[f]	0.71 (0.46-1.09)	0.72 (0.47-1.10)[d]
Hip abduction (kg/kg)[b]	0.88 (0.63-1.24)	0.88 (0.62-1.24)[f]	1.02 (0.68-1.55)	1.04 (0.69-1.57)[d]

[a]Values in parentheses are 95% CIs and significant results are marked in bold; [b]Body mass normalized values; [c]Strength difference between stronger and weaker leg; [d]Adjustment factors: previous acute ankle injury and age; [e]Adjustment factors: previous acute ankle injury, age and height; [f]Adjustment factors: previous acute ankle injury, age, height and sport

5.3.4 Risk factor analyses for female injuries

In the adjusted risk factor analyses, greater 1RM leg press and difference between legs in maximal hip abduction strength increased the risk of noncontact acute ankle injury (HR for 1 SD increase = 1.4, 95% CI 1.0–2.0, P = 0.03, and 1.4, 95% CI 1.0–2.0, P = 0.03, respectively; Table 11). However, according to the ROC curve analysis, the combined sensitivity and specificity of the risk factors were "poor" and "fail" (AUCs of 0.63 for 1 RM leg press strength and 0.57 for strength difference between legs in hip abduction).

Table 11. Unadjusted and adjusted hazard ratios (per one standard deviation increase), with 95% confidence intervals for strength variables for any type of acute and noncontact acute ankle injury in female athletes[a]

	Any type		Noncontact	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Athlete as a unit of analysis				
Leg press (kg/kg)[b]	1.23 (0.93-1.63)	1.32(0.96-1.80)[e]	**1.38 (1.01-1.88)**	**1.44 (1.03-2.02)**[d]
Quadriceps between-leg difference (N·m)[c]	0.84 (0.59-1.18)	0.85 (0.62-1.16)[e]	0.85 (0.59-1.22)	0.86 (0.62-1.21)[d]
Hamstrings between-leg difference (N·m)[c]	1.00 (0.76-1.30)	1.00 (0.77-1.31)[e]	0.97 (0.70-1.34)	0.97 (0.70-1.34)[d]
Hip abduction between-leg difference (kg)[c]	1.15 (0.88-1.50)	1.14 (0.87-1.49)[e]	**1.44 (1.05-1.98)**	**1.44 (1.03-2.00)**[d]
Leg as a unit of analysis				
Quadriceps (N·m/kg)[b]	0.88 (0.68-1.15)	0.88 (0.66-1.17)[f]	0.84 (0.61-1.14)	0.85 (0.61-1.18)[d]
Hamstrings (N·m/kg)[b]	0.91 (0.69-1.19)	0.90 (0.67-1.21)[f]	0.84 (0.61-1.17)	0.82 (0.58-1.17)[d]
HQ ratio (%)	1.02 (0.77-1.35)	1.02 (0.77-1.37)[f]	0.98 (0.71-1.36)	0.95 (0.67-1.33)[d]
Hip abduction (kg/kg)[b]	1.09 (0.84-1.42)	1.10 (0.84-1.43)[f]	1.21 (0.88-1.65)	1.21 (0.88-1.65)[d]

[a]Values in parentheses are 95% CIs and significant results are marked in bold; [b]Body mass normalized values; [c]Strength difference between stronger and weaker leg; [d]Adjustment factors: previous acute ankle injury, age and height; [e]Adjustment factors: previous acute ankle injury, age, height and sport; [f]Adjustment factors: previous acute ankle injury, age, height, sport and playing at adult level

5.4 Knee injury history, function and knee injury (Study IV)

5.4.1 Injury characteristics in males

A total of 18 new acute knee injuries occurred, and 10 of these were noncontact injuries. In addition, two athletes had reinjured the same knee once. There were five bone bruises, five joint or ligament sprains, four meniscal lesions, one ACL injury, one patellar dislocation, one intra-articular fracture and one unspecified acute knee injury. The incidence rates for any type of acute and noncontact acute knee injury were 0.3 (95% CI 0.2–0.4) and 0.2 (95% CI 0.1–0.3) injuries per 1,000 player-hours, respectively.

5.4.2 Injury characteristics in females

There were 37 new acute knee injuries in 32 athletes (five athletes had both knees injured), and 30 occurred in noncontact situations. Three athletes had reinjured the same knee once. In addition to 16 ACL injuries, 8 bone bruises, 6 joint or ligament sprains, 1 posterior cruciate ligament injury, 1 meniscal lesion and 5 unspecified acute knee injuries were diagnosed. The incidence rates for any type of acute and noncontact acute knee injury were 0.6 (95% CI 0.4–0.8) and 0.5 (95% CI 0.3–0.7) injuries per 1,000 player-hours, respectively.

5.4.3 Risk factor analyses for male injuries

In the unadjusted risk factor analyses, previous acute knee injury was associated with a 5.8-fold increase in risk of any type of acute knee injury (HR 5.8, 95% CI 2.2–15.3, P < 0.001). Also, lower KOOS Pain, ADL, Sport/Rec and QOL subscale scores increased the risk of any type of injury in the same knee. In the unadjusted analyses, the same risk factors were also associated with increased risk of noncontact acute injury in the same knee (Table 12). Due to the low number of acute knee injuries in males, adjusted analyses were not performed.

Table 12. Unadjusted hazard ratios, with 95% confidence intervals for previous acute knee injury and scores of the Knee Injury and Osteoarthritis Score subscales for any type of acute and noncontact acute knee injury in male athletes[a]

	Any type	Noncontact
	HR	HR
Previous acute knee injury[b]	**5.82 (2.21-15.27)**	**7.19 (1.84-28.04)**
KOOS[c]		
Pain	**1.76 (1.25-2.49)**	**2.31 (1.47-3.64)**
Symptoms	1.10 (0.68-1.80)	1.30 (0.74-2.31)
ADL	**1.50 (1.20-1.89)**	**1.64 (1.26-2.15)**
Sport/Rec	**1.76 (1.26-2.46)**	**2.04 (1.30-3.18)**
QOL	**1.94 (1.38-2.73)**	**2.33 (1.40-3.90)**

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score. Values in parentheses are 95% CIs. Significant results are marked in bold. HR, hazard ratio; [b]Athlete as a unit of analysis. Club considered as a cluster; [c]ADL, Activities of Daily Living. Sport/Rec, Sport and Recreation. QOL, Knee-Related Quality of Life. Leg as a unit of analysis. HR per 1 SD decrease

5.4.4 Risk factor analyses for female injuries

In the adjusted risk factor analyses, previous acute knee injury increased the risk of any type of acute knee injury by 2.6-fold (HR 2.6, 95% CI 1.3–5.2, P = 0.01; Table 13). Female athletes with previous acute knee injury and a probability of having a new acute knee injury was 30.4% (95% CI 21.0–41.9). Correspondingly, in those who did not have a previous injury, the probability was 13.1% (95% CI 9.9–17.2). However, ROC curve analysis showed an AUC of 0.61, indicating "poor" combined sensitivity and specificity of previous acute knee injury. In the unadjusted analyses, a lower KOOS ADL subscale score increased the risk of any type of acute knee injury. The trend was similar in the adjusted analysis, but the observed HR was not statistically significant.

In the adjusted risk factor analysis, previous acute knee injury also increased the risk of noncontact acute knee injury (HR 2.4, 95% CI 1.1–5.0, P = 0.03; Table 13), but ROC curve analysis showed an AUC of 0.61, indicating "poor" combined sensitivity and specificity of the risk factor.

Table 13. Unadjusted and adjusted hazard ratios, with 95% confidence intervals for previous acute knee injury and scores of the Knee Injury and Osteoarthritis Score subscales for any type of acute and noncontact acute knee injury in female athletes[a]

	Any type		Non-contact	
	HR	Adjusted HR	HR	Adjusted HR
Previous acute knee injury[b]	**2.67 (1.33-5.37)**	**2.58 (1.28-5.21)**[d]	**2.40 (1.13-5.07)**	**2.35 (1.11-4.97)**[f]
KOOS[c]				
Pain	1.26 (0.94-1.68)	1.12 (0.80-1.56)[e]	1.14 (0.81-1.61)	0.97 (0.65-1.45)[g]
Symptoms	1.25 (0.93-1.67)	1.12(0.82-1.52)[e]	1.15 (0.83-1.61)	1.01 (0.71-1.43)[g]
ADL	**1.29 (1.03-1.62)**	1.22 (0.97-1.54)[e]	1.23 (0.95-1.60)	1.13 (0.85-1.49)[g]
Sport/Rec	1.27 (0.95-1.68)	1.15 (0.84-1.58)[e]	1.25 (0.92-1.70)	1.13 (0.80-1.58)[g]
QOL	1.34 (1.00-1.79)	1.16 (0.84-1.60)[e]	1.33 (0.98-1.81)	1.19 (0.84-1.67)[g]

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score. Values in parentheses are 95% CIs. Significant results are marked in bold. HR, hazard ratio; [b]Athlete as a unit of analysis. Club considered as a cluster; [c]ADL, Activities of Daily Living. Sport/Rec, Sport and Recreation. QOL, Knee-Related Quality of Life. Leg as a unit of analysis. HR per 1 SD decrease; [d]Adjustment factors: age and BMI; [e]Adjustment factors: previous acute knee injury and age; [f]Adjustment factor: age; [g]Adjustment factor: previous acute knee injury

6 DISCUSSION

This thesis provides important insights into the epidemiology of youth floorball injuries, as well as intrinsic risk factors for acute knee, ACL and ankle injuries in youth floorball and basketball athletes. There were several important findings. First, the incidence of acute knee and ankle injuries is high in youth floorball athletes. Second, lower maximal hip abduction strength increased the risk of any type of acute knee injury in youth basketball and floorball athletes. Third, greater 1RM leg press and maximal isokinetic quadriceps strength increased the risk of any type of acute ankle injury in male youth basketball and floorball athletes, while greater 1RM leg press strength and greater difference between legs in maximal hip abduction strength increased the risk of noncontact acute ankle injury in youth female counterparts. Finally, previous acute knee injury increased the risk of any type of acute and noncontact acute knee injury in youth female athletes.

6.1 Floorball injuries in youth athletes

The incidence rates of acute injuries in youth floorball athletes in this study are similar to those reported in the literature (1.9 and 2.4 acute injuries per 1,000 player-hours in male and female youth handball athletes, respectively; Olsen et al., 2006). The total (acute and overuse) injury incidence rates of 3.0 to 3.6 per 1,000 player-hours previously reported in male and female youth basketball athletes (Messina et al., 1999; Yde & Nielsen, 1990) are also similar to those of this study because the proportion of overuse injuries in floorball has been reported to be 17%–30% of all injuries (Pasanen et al., 2008; Snellman et al., 2001; Wikström & Andersson, 1997). However, the injury risk in youth floorball athletes seems to be lower than in youth soccer athletes. Emery et al. (2005) and Yde and Nielsen (1990) both found an incidence rate of 5.6 per 1,000 player-hours for any type of injury in a group of male and female youth soccer athletes, and Clausen et al. (2016) found an incidence rate as high as 6.2 per 1,000 player-hours for acute injury in female youth soccer athletes.

The injury incidence rates in male youth floorball athletes found in this study are lower than those of previous epidemiologic studies in adult male athletes (Pasanen et al., 2016; Tranaeus et al., 2016; Wikström & Andersson, 1997). This was expected, considering that total (acute and overuse) injury incidence was reported in these studies. In contrast, the injury incidence in female athletes was in line only with the total incidence of 3.9 per 1,000 player-hours reported by Tranaeus et al. (2016) but considerably higher than expected compared to 1.9 and 2.5 per 1,000 players-hours reported by Pasanen et al. (2016) and Wikström and Andersson (1997), respectively. Particularly, the risk of sustaining an acute injury during games seems to be considerably higher in youth compared to 13.4 to 40.3 per 1,000 player-hours for any type of injury reported in adult female floorball athletes (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001).

In line with previous epidemiologic studies (Pasanen et al., 2008; Pasanen et al., 2016; Snellman et al., 2001; Tranaeus et al., 2016), the ankle and knee were the most injured body parts in youth floorball athletes, regardless of sex. In contrast, Wikström and Andersson (1997) found that the shoulder was the second most common injury location in male athletes, but overall, only 28 acute injuries in males were reported. The finding that joint/ligament sprain and muscle/tendon strain are the most common acute injury types in youth floorball athletes is supported by two previous studies in adult athletes (Pasanen et al., 2008; Snellman et al., 2001). In contrast, Pasanen et al. (2016) reported contusion as the second most common injury type in floorball if all injuries (not only time loss) were taken into account. However, this finding is related to the injury definition because athletes typically can continue playing and practicing after contusion.

The proportion of severe injuries causing long absence (>28 days) from sport was considerably higher in youth compared to that previously found in adult floorball athletes (Pasanen et al., 2008; Pasanen et al., 2016; Tranaeus et al., 2016). Among high school athletes of various sports, knee injuries have been found to be most often severe (Darrow et al., 2009; Swenson et al., 2013), and females are more prone to sustaining these injuries than males (Ingram et al., 2008). ACL injuries are especially well known to be more common in youth female athletes compared to their male counterparts (Agel et al., 2005; Swenson et al., 2013). All eight ACL injuries in this study occurred in females, supporting previous findings.

The proportion of acute injuries occurring without direct contact to the injured body part in youth floorball athletes is notable and more than previously reported (45%) in adult floorball athletes (Pasanen et al., 2008; Wikström & Andersson, 1997). It is possible that the game is less physical, including fewer tackles and collisions with opponents, for youth compared to adult floorball. This highlights the importance of proper technique and movement control, especially in youth athletes during sudden direction changes and other fast movements in which these injuries occur. In addition, the proportion of noncontact knee and ankle ligament injuries seems to be considerably higher in youth floorball athletes compared to youth athletes from other team sports (Cloke et al., 2009; Swenson et al., 2013). However, approximately 70% of ACL injuries have been reported to occur in noncontact situations (Agel et al., 2005; Alentorn-Geli et al., 2009; Griffin et al., 2000).

6.2 Muscle strength and acute knee and ACL injury

In line with a previous study in professional male soccer athletes (Bakken et al., 2018), no association between isokinetic hamstrings or quadriceps strength and any type of acute knee injury was found in male athletes in this study. However, in contrast to Bakken et al.'s (2018) study, lower hip abductor strength increased acute knee injury risk in males in this study. Because body mass normalized hip abductor strength has been shown to increase significantly in youth athletes with age (Bittencourt et al., 2016b; Brent et al., 2013), it is possible that the difference between stronger and weaker athletes in hip abduction strength becomes easier to measure in youth athletes than in professional athletes. Lower hip abduction and external rotation strength have also been associated with increased risk of any type of back or LE injury (Leetun et al., 2004) and noncontact ACL injury (Khayambashi et al., 2016) in groups of male and female athletes, but separate analyses for males and females were not made in these studies. In contrast to the present study, Ekstrand and Gillquist (1983) found that male athletes who sustained acute noncontact knee injury had lower isokinetic quadriceps strength compared to uninjured athletes. However, direct comparisons with Ekstrand and Gillquist's (1983) study may be unreliable because they reported strength values as N·m/body area.

In the present study, no association was found between any measured muscle strength variable and acute knee or ACL injury in female athletes. These findings are supported by previous studies investigating the same strength variables as risk factors for any type of knee injury (Nilstad et al., 2014) and noncontact ACL injury (Steffen et al., 2016) in elite female athletes. In addition, Uhorchak et al. (2003) and Vacek et al. (2016) reported no association between measured strength variables and noncontact ACL injury in female military cadets and female athletes from various sports, respectively. In contrast to this study, lower HQ strength ratio has previously been suggested to be a risk factor for ACL injury in female athletes (Myer et al., 2009; Söderman et al., 2001). However, only five ACL injuries were reported in Söderman et al.'s (2001) study. In Myer et al.'s (2009) study, isokinetic hamstring and quadriceps strength was measured with a high angular velocity of 300°/s—which can be thought to better correspond to fast situations in sport, in which acute knee injuries typically occur. However, Koga et al. (2010) pointed out that ACL injuries occur quickly, on average 40 ms after initial ground contact. Therefore, it is unlikely that a different measurement protocol explains the finding of Myer et al.'s (2009) study.

Greater hip abduction strength has also been associated with increased risk of noncontact ACL injuries in Japanese youth female athletes (Nakase et al., 2020; Shimozaki et al., 2018). However, in contrast to the present study, athletes' exposure times were not recorded in these studies. Athletes with greater hip abduction strength might also have practiced and played more; thus, they might have been at injury risk for a longer period than uninjured athletes. In addition, Ryman Augustsson and Ageberg (2017) reported that lower 1RM barbell squat strength increased the risk of acute knee injury in female athletes. Squat exercise has been shown to generate greater quadriceps and hamstrings activity and further greater tibiofemoral and patellofemoral compressive forces, which may provide enhanced knee stability during the squat compared to the leg press exercise (Escamilla et al., 2001). Thus, an athlete with great 1RM leg press strength, unlike an athlete with great 1RM barbell squat strength, may not necessarily have such great knee stability, which may prevent the athlete from sustaining an acute knee injury.

6.3 Muscle strength and acute ankle injury

The findings concerning male athletes in the present study are unique. Although greater quadriceps strength has been previously associated with increased risk of hamstring strain (Freckleton & Pizzari, 2013) and any type of LE injury (Bakken et al., 2018), greater quadriceps or 1RM leg press strength have not been described as risk factors for ankle injury. It might be argued that older junior-aged male athletes are stronger and that they practice and play more (even in adult league teams), thus being at risk of getting an injury for a longer period, but no strong correlations between male athletes' age and these strength variables were found in additional analyses, indicating that age alone is not sufficient to explain this finding. Nevertheless, stronger athletes might have been more mature and skilled otherwise. Strong athletes may also be able to run and change direction faster, leading to greater mechanical forces, and in this way, the injury risk may increase. In addition, being strong does not necessarily mean that an athlete has a proper landing and direction change technique. Poor technique, combined with greater muscle mass and higher speed, may increase ligament loading and ankle injury risk in stronger athletes compared to weaker lightweighted athletes.

Supporting the findings of this study, De Ridder et al. (2017) and McHugh et al. (2006) found no association between hip abductor strength and lateral ankle sprain in male soccer athletes, but the latter reported that lower hip extensor strength increased the risk of these injuries. Hip extension strength was not measured in this study, but considering that greater 1RM leg press strength increased the risk of ankle injury, it is likely that greater, rather than lower, hip extension strength might have increased the risk of these injuries. In contrast, Powers et al. (2017) reported an association between lower hip abduction strength and the increased risk of noncontact lateral ankle sprain in male soccer athletes. Although the hip strength measurement in Powers et al.'s (2017) study was done with a short lever arm placing the dynamometer pad on the distal femur, the reported average hip abduction strength values were almost two times greater compared to the present study. Because lower values could be expected using the short lever arm (Krause et al., 2007), athletes in Powers et al.'s (2017) study might have been considerably stronger than in the present study, which might have influenced the risk of ankle sprain.

The findings concerning female athletes extend previous findings from female elite soccer athletes (Nilstad et al., 2014). No association between isokinetic quadriceps or hamstrings strength, HQ ratio or hip abduction strength and any type of ankle injury was found in Nilstad et al.'s (2014) study, although the athletes were considerably older compared to the present study. In contrast to Nilstad et al.'s (2014) study, greater 1RM leg press strength increased the risk of acute noncontact ankle injury in female athletes in this study. Female athletes have different kinematic profiles with greater hip adduction and hip internal rotation, as well as knee valgus and ankle dorsiflexion and pronation angles, while running and during landings and rapid direction changes compared to their male counterparts (Ferber et al., 2003; Kernozek et al., 2005; McLean et al., 2005). Gender differences have also been reported to exist in muscle activation in many LE muscles during unanticipated side-cut and cross-cut maneuvers (Landry et al., 2009). Because noncontact ankle injuries typically occur in these movements, it seems that proper muscle activation, rather than greater maximal strength, could prevent these injuries.

Greater side-to-side difference between legs in hip abduction strength has not been previously presented as a risk factor for ankle injury in both male and female athletes. This finding should be interpreted with caution. It is possible that these athletes had strength imbalances in other LE or core muscles as well. This strength imbalance can also be a compensatory mechanism for inadequate or false movement patterns.

6.4 Previous injury, knee function and acute knee injury

The nearly six-fold increased risk of sustaining any type of acute knee injury in male athletes with a previous acute knee injury in the unadjusted analyses was considerably higher than previously reported in adult male soccer (Arnason et al., 2004; Hägglund et al., 2006) and basketball athletes (Meeuwisse et al., 2003). In addition, Engebretsen et al. (2011) found no association between any type of previous and acute knee injury in adult male soccer athletes. However, Kucera et al. (2005) studied a group of youth (<18 years) soccer athletes and also presented a nearly six-fold increased risk for acute knee injury in previously knee-injured, compared to uninjured, athletes. Although both sexes were included in the study group in Kucera et al.'s (2005) study, there is evidence that previously knee-injured male youth athletes might have a considerably higher risk for acute knee injury compared to adult male athletes. This may be due to the dropout of those with severe or multiple injuries at a younger age from sports.

In this study, lower KOOS subscale scores in four of five subscales increased the risk of any type of acute injury in the same knee in male athletes. In contrast, Engebretsen et al. (2011) reported that only a lower KOOS Pain subscale score was associated with acute knee injury risk in the unadjusted models, and no associations were found in the adjusted models. However, the athletes in their study were considerably older than those in the present study, with a mean age of 24 years. It is obvious that adult athletes with longer sport careers are more likely to have sustained previous knee injuries compared to younger athletes. In addition to the dropout of severe cases, rehabilitation of previous knee injuries may also be more successful in experienced adult athletes, and therefore, they might have had fewer knee problems and, thus, higher KOOS subscale scores in previously injured knees.

The findings concerning injury history in female athletes correspond with previous findings from studies in youth female soccer athletes (Clausen et al., 2016; Steffen et al., 2008). Steffen et al. (2008) found that a history of previous knee injury increased the risk of any type of injury to the same knee by 40%, and Clausen et al. (2016) reported a more than three-fold increase in the risk of sustaining any type of knee injury in previously injured, compared to uninjured, athletes. Hägglund and Walden (2016) also studied female youth soccer athletes but found no association between previous and new acute knee injuries in the adjusted analyses, although a 2.5-fold increase in injury risk was found in the unadjusted analyses. In addition, no association between previous and new knee sprains (Faude et al., 2006) or previous and new knee injuries (Nilstad et al., 2014) are reported in adult female soccer athletes. Altogether, the findings of the present and previous studies indicate that the risk of acute knee injury associated with previous knee injury might be lower in female athletes than in male athletes.

Lower scores in all KOOS subscales (Steffen et al., 2008) and, especially, in Sport/Rec, QOL and most ADL subscales (RR 5.38, 95% CI 1.73–7.46, for scores <80; Clausen et al., 2016) have been associated with increased risk of any type of knee injury. However, in contrast to this study, previous injury was not treated as a confounder in the analyses in these studies. As presented in the additional analyses in the present study, strong associations exist between previous acute knee injury and all KOOS subscale scores in both sexes. Considering a borderline association between a lower KOOS ADL subscale score and the risk of acute knee injury in this study, a lower ADL subscale score surprisingly seems to best predict future acute knee injury in youth female athletes. However, difficulties with ADL functions are typically mild in adolescence. Therefore, the ADL subscale score may not reflect physical function in youth athletes (Frobell et al., 2010).

6.5 Clinical implications

The findings of Study I help to design injury prevention strategies for youth floorball athletes. Coaches, physicians and physical therapists should focus on reducing acute knee and ankle injuries in these athletes not only because these injuries are the most common but also because they, in most cases, occur without direct contact. From the perspective of injury prevention, it is essential to know the mechanisms of these injuries in youth floorball athletes (Bahr & Krosshaug, 2005), and based on the findings of this study, the mechanisms seem to be different compared to those involved in injuries in adult floorball athletes and youth athletes in other team sports. Injury prevention programs should also consider that youth female floorball athletes are more susceptible to sustaining an acute injury during games compared to males. In addition, treatment, rehabilitation and return to sport should receive special attention to avoid recurrent injury, especially in the case of ankle injury in these athletes.

Because lower hip abductor strength was associated with increased risk of any type of acute knee injury in male youth athletes in Study II, regular hip abductor strength exercises can be recommended for these athletes. Although stronger male and female athletes measured by 1RM leg press strength were at an increased risk of sustaining an acute ankle injury in Study III, this does not mean that these strength exercises should not be done. Correspondingly, despite the findings from Study III, male youth athletes should not avoid quadriceps strength exercises, and youth female athletes should not concentrate on strengthening the hip abductor muscles of the weaker leg. It should be noted that while maximal muscle strength was measured in this study, muscle strength training usually contains exercises with low or no additional weights by concentrating on proper technique with gradually increasing volume and intensity in neuromuscular injury prevention programs (Lauersen et al., 2018). As a result of increased limb length and body mass in growth spurts during adolescence, moments of inertia in limbs increasely affect limb dynamics and muscle strength required to perform movements (Hawkins & Metheny, 2001). At the same time, sensorimotor functions continue to develop, and there may be periods of regressions in some of these, which may contribute to the injury risk (Quatman-Yates et al., 2012). Therefore, neuromuscular training, including low- or body weight strength exercises, can be recommended, especially for youth athletes.

Neuromuscular warm-up programs have been shown to be effective in the prevention of acute injuries in youth floorball (Åkerlund et al., 2020) and basketball (LaBella et al., 2011), as well as in other youth team-sports athletes (Emery & Meeuwisse, 2010; Olsen et al., 2005). According to Brunner et al.'s (2019) review, these programs can specifically prevent acute knee, ACL and ankle injuries. The mechanisms by which strength training works are thought to be both direct (the strengthening of certain muscles) and indirect (strength training–related effect of improved coordination, enhanced techniques in playing situations, the strengthening of adjacent tissues and better psychological perception of high-risk situations; Lauersen et al., 2018).

Based on the findings of Study IV, the treatment and rehabilitation of the present knee injury and secondary prevention of reinjury should be emphasized. Previously knee-injured youth athletes should especially be motivated to engage in neuromuscular training to prevent reinjury.

However, regardless of significant associations between muscle strength and acute knee or ankle injury in youth athletes, a substantial overlap between the test results in injured and uninjured athletes was found, leading to "fail"-to-"poor" combined sensitivity and specificity for these tests (i.e., the tests can correctly classify

<70% of injured and uninjured athletes). Therefore, in clinical practice, muscle strength, as measured in the present study, cannot be recommended alone as an injury screening tool for acute knee and ankle injuries in youth athletes. Similarly, previous acute knee injury cannot be recommended alone to identify the occurrence of new acute knee injury in youth female athletes.

6.6 Strengths and limitations

The studies of this thesis had several strengths. First, all the data were collected prospectively. Second, the sample size was relatively large, the three-year follow-up time relatively long and athletes' dropout rate low. Third, exposure data were collected individually, and the accuracy of injury data collection was good because the study physicians contacted coaches of participating teams once a week and communication was rather easy to carry out in the small area. Fourth, the muscle strength risk factors in Studies II and III were measured with standard and simple procedures that are easy to use in clinical practice. Particularly, the questionnaires presented in Study IV are simple and fast tools for identifying injury risk in youth and nonprofessional athletes. In addition, individually collected exposure data enabled the use of Cox regression in statistical analyses in Studies II–IV. Furthermore, the athlete or the leg was used as a unit of these analyses, depending on the risk factor (Bahr & Holme, 2003).

This thesis also had limitations. In Study I, athletes' inconsistent follow-up time was one limitation. Female teams completed all three follow-up years, but male teams were involved in only one- or two-year follow-up. However, the total follow-up time in males and females was relatively similar. Another limitation was that only half of the injuries were diagnosed by clinical examination; the remaining half were diagnosed by telephone interview. Thus, there is the possibility of precision uncertainty in reporting injuries, such as injury mechanism or type. In addition, because the coaches reported injuries, some minor injuries may have not been reported. Finally, Study I's participants represent a relatively small proportion of the youth floorball athletes in Finland. Thus, team habits and training conditions might be different in a larger population, probably affecting the injury risk.

One limitation concerning isokinetic quadriceps and hamstrings strength measurements in Studies II and III was that only maximal muscle strength was measured. Maximal strength may provide limited information about muscle performance during the full range of knee motion because the largest quadriceps strength deficits have been established at knee flexion angles less than 40° after ACL injury (Eitzen et al., 2010). Another limitation was that isokinetic quadriceps and hamstrings strength was measured only with an angular velocity of 60°/s. It is obvious that much higher velocities are involved in knee motions in ball sports. In addition, eccentric isokinetic strength could have also been measured.

Hip strength measurement in Studies II and III also had limitations. First, maximal hip abduction could have also been measured in the side-lying position (Khayambashi et al., 2016; Powers et al., 2017) or with the hip in flexion because in real knee or ankle injury situations, the hip is probably slightly in flexion rather than in the straight position. Second, the influence of the lever arm on hip abduction strength was not considered because hip abduction strength was recorded as kg/kg—not N·m/kg, as in some studies (Bakken et al., 2018; McHugh et al., 2006; Nakase et al., 2020; Shimozaki et al., 2018). Third, hip extension and external rotation strength, which have been associated with lateral ankle sprain (De Ridder et al., 2017) and noncontact ACL injury (Khayambashi et al., 2016), respectively, were not measured.

In addition, the prevalence of acute knee injuries in Studies II and IV, as well as ACL injuries in Study II, was relatively low, limiting the statistical power of the studies. Therefore, other than rather strong risk factors might not have been detected (Bahr & Holme, 2003). For the same reason, the number of adjustment factors had to be decreased, and some adjusted analyses could not have been performed for male knee injuries to maintain the validity of the analyses (Peduzzi et al., 1995). Moreover, the strength measurements were not repeated; thus, the strength values might have changed during the follow-up because athletes became older and more strength training might have been adopted in exercise programs.

A limitation in Study IV was that self-reported injury history relied on the athletes' recall, and therefore, some previous injuries might have gone unreported. However, only previous acute knee injuries were asked, which likely minimized the risk of recall bias. In addition, because the KOOS questionnaire was developed for studies concerning treatment of knee injuries and for long-term follow-up of patients with osteoarthritis (Roos et al., 1998), it may have limited value for assessment of knee function in youth and mainly knee-healthy athletes.

7 MAIN FINDINGS AND CONCLUSIONS

In response to the aims of the thesis, the main findings and conclusions can be summarized as follows:

1. Incidence of acute knee and ankle injuries is high in youth floorball athletes. Most of these injuries occur through the noncontact/indirect contact mechanism. Compared to males, female athletes had significantly higher game injury and joint/ligament injury rates.

2. Lower maximal hip abduction strength increased the risk of any type of acute injury in the same knee for male youth basketball and floorball athletes. However, according to the sensitivity and specificity analysis, maximal hip abduction strength cannot be used alone as a screening tool for an acute knee injury in these athletes. None of the measured muscle strength risk factors were associated with acute knee or ACL injury in female youth basketball and floorball athletes.

3. Greater 1RM leg press and maximal isokinetic quadriceps strength increased the risk of any type of acute ankle injury in male youth basketball and floorball athletes, while greater 1RM leg press strength and greater difference between legs in maximal hip abduction strength increased the risk of noncontact acute ankle injury in female youth basketball and floorball athletes. However, according to the sensitivity and specificity analysis, these risk factors cannot be used alone as screening tools for an acute ankle injury in these athletes.

4. Previous acute knee injury increased the risk of any type of acute and noncontact acute knee injury in youth female basketball and floorball athletes. However, according to the sensitivity and specificity analysis, previous acute knee injury cannot be used alone as a screening tool for an acute knee injury in these athletes. None of the KOOS subscale scores were associated with acute knee injury risk in youth female basketball and floorball athletes.

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Original research

Acute injuries in Finnish junior floorball league players

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ABSTRACT

Objectives: To investigate the incidence and characteristics of acute time-loss injuries in Finnish junior floorball league players.
Design: Prospective cohort study with 3-year follow-up.
Methods: One hundred and eighty-six female and male players (mean age 16.6 ± 1.4) took part in the follow-up study (2011–2014). The training hours and games were recorded on a team diary. Floorball related acute injuries were registered and verified by a research physician. The injury incidence was expressed as the number of injuries per 1000 h of exposure. Incidence rate was calculated separately for games and practices, and for males and females.
Results: One hundred and forty-four acute time-loss injuries occurred. Injury incidence was 26.87 (95% CI 20.10–33.63) in junior league games, and 1.25 (95% CI 0.99–1.52) in team practices. Female players had significantly higher game injury rate (IRR 1.88, 1.12–3.19) and joint/ligament injury rate (IRR 1.70, 1.07–2.73) compared to males. Eighty-one percent of the injuries affected the lower limbs. The ankle (37%), knee (18%), and thigh (14%) were the most commonly injured body sites. More than half of injuries involved joint or ligaments (54%). Twenty-six percent of the injuries were severe causing more than 28 days absence from sports. Eight anterior cruciate ligament ruptures of the knee occurred among seven female players.
Conclusion: The study revealed that risk of ankle and knee ligament injuries is high in adolescent floorball, specifically among female players.

1. Introduction

Floorball is a fast-paced indoor team sport with growing popularity worldwide. The International Floorball Federation (IFF) was founded in 1986 by the national floorball associations of Finland, Sweden, and Switzerland. Today, the IFF has national member associations in 65 countries (personal communication/the IFF). Floorball is one of the most popular team sports in Finland. In 2016 the Finnish Floorball Association had over 850 registered clubs with 54 900 licensed players, of which the number of junior aged players was 28 900 (personal communication/the Finnish Floorball Association). Moreover, floorball is widely played in schools, workplaces and leisure time, and the overall number of Finnish floorball players is estimated to be approximately 350 000 (Finnish Floorball Federation, www.floorball.fi).

During the past couple of decades floorball has developed from a recreational activity into competitive sport that requires high degree of physical and motor performance abilities. The movement patterns of the field players comprise running in multiple planes of motion, sudden accelerations and decelerations, frequent changes of direction, and handling a stick and the ball during these fast-paced motions. Goalkeepers play mostly on their knees and they save the goal with their hands and body.

In spite of growing popularity, the number of studies on floorball injuries is low. Four prospective studies on epidemiology of floorball injuries have been previously performed among licensed players in Finland and Sweden.[1–4] These investigations have revealed that the most of the acute injuries affect the lower limb, and the ankle, knee and thigh are the most common sites of injuries.[1–4] One of the most severe sports injuries is a rupture of

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anterior cruciate ligament (ACL) of the knee which often leads to a long-term absence from sports and increases the risk for degerenative joint disease.[5–7] According to the previous studies, the risk of ACL injuries is high in floorball, especially among female players.[3–4]

Floorball has also been reported to belong to the highest risk group of sports concerning sports-related eye-injuries.[8–10] According to a Finnish study at the Ophthalmology Emergency Clinic in Helsinki, floorball caused 45% of all sports-related eye-injuries during a 6-months study period.[8] Correspondingly, in a Swedish study, 56% of sports-related eye-injuries in Jonköping county from 2008 through 2011 occurred in floorball.[9] A cross-sectional study in Sweden and Switzerland revealed that 28% out of 506 field players in adult series had suffered an injury to the eye or its vicinity at least once.[10] Protective eyewear for floorball has been available for a decade, but use of them is still relatively scarce. Since 2008 protective eyewear has been required in the Finnish junior series among players whose year of birth is 1999 or later, but for older players use of eye protection is not mandatory (personal communication/the Finnish Floorball Association).

The above noted previous studies on floorball injuries have focused on adult top level leagues whereas detailed information on injuries in junior floorball leagues is lacking. Nevertheless, knowledge on epidemiology of typical injuries in particular target groups is crucial for creating effective injury prevention methods. The purpose of the present study was to investigate the incidence and characteristics of acute floorball injuries in female and male junior league players.

2. Materials and methods

This study is a part of a large PROFITS-study (Predictors of Lower Extremity Injuries in Team Sports) carried out in Finland during 2011–2015. Detailed information of the PROFITS-study is described elsewhere.[11] The study was approved by the ethics committee of the Pirkanmaa Hospital District, Tampere, Finland (ETL code R10169), and was performed in accordance with the Declaration of Helsinki.

Eight adolescent floorball teams from three sports clubs from Tampere City district, Finland, were invited to participate in the investigation. The invited study cohort consisted of six male teams and two female teams from the two highest junior league levels. One male team declined to participate. Thus, seven teams were studied during the three consecutive years (2011–2014). Both female teams played in U20 league of 10 teams, three male teams played in U20 league of 12 teams, and two male teams played in U18 league of 12 teams. Teams entered the study either in May 2011, April/May 2012 or April/May 2013. Female teams completed all three follow-up years, two male teams completed two follow-up years, and the remaining three male teams completed one follow-up year. Final participation was based on an informed consent of each player (and parent/guardian if the player was <18 years of age).

Altogether, 193 players entered the study. We included junior players if they were official members of the participating junior teams and played in junior series during the follow-up. Seven players were excluded because they did not play in junior series. Consequently, 186 young floorball players (mean age 16.6 ± 1.4) were included in the study: 111 male and 75 female players. The cohort comprised 18 goalkeepers and 168 field players. Twenty-one female players and 10 male players played in both junior and adult leagues. The players ranged in age from 13 to 20 years during the follow-up. Eight of the players (7 females; 1 male) entered the study at age of 13–14 years. Of the participating players 112 completed one; 45 two; and 29 three follow-up years. Altogether, 289 athlete-years were followed in the study.

The players completed a questionnaire about background information[11] at the study onset. The questionnaire included questions about age, sex, starting age, playing position, playing level, and previous injuries. During the follow-up team coaches recorded player participation in team events on a team diary and noted all injured players. An injury was defined as any acute injury occurring during a junior game or practice making the player unable to participate in floorball training or playing during the following 24 h. All injured players were entitled to free appointment with a physician specialized to sports medicine (J.P., P.K.) at the Medical Center of the UKK Institute.

A research physician (J.H.) contacted the team coaches weekly to check new injuries. For any time-loss injury occurring during team practices or games, the physician contacted the injured player by phone and interviewed her/him using a structured form[3,11,12] to obtain detailed data and description of the injury. The location, type, place and time of occurrence, injury circumstances and mechanism, treatment and diagnosis, time loss from sports, and whether the injury was a first-time or a recurrent injury were registered. The injury mechanisms were reported as contact (direct contact to the injured body region), indirect contact (contact with other body parts) or non-contact.[13]

An injury of same site and same type as a prior injury that occurred after a player's full return in floorball from a prior injury was defined as a recurrent injury.[14] The recurrence of injuries was classified as early recurrence (a recurrent injury that occurred within 2 months of a player's full return); late recurrence (a recurrent injury occurred within 2–12 months after a player's full return); and delayed recurrence (a recurrent injury occurred more than 12 months after a player's full return). Contusions and lacerations were always classified as a first-time injury, whether they were recurring or first-time injuries. The severity of injuries was defined in four categories: minimal injury (an injury causing absence of 1–3 days); mild injury (4–7 days); moderate injury (8–28 days); and severe injury (>28 days).[14]

The exposure time on team practices were collected individually for each player. The coach registered players' attendance at each team event, as well as duration of training session and type of training (floorball training; strength/conditioning/warm-up and cool-down exercises). Individual practices performed outside the scheduled team events were not included in the exposure data. The time of exposure to floorball games was calculated for entire teams. The total number of games played by each junior team was collected. Then the exposure time was calculated as follows: each game lasts 60 min of actual play and there are always six players on the court (a goalkeeper and five field players) resulting in total exposure of 6 h per game per team.

Data were analyzed using SPSS Statistics Software, version 22 (SPSS, Chicago, Illinois) and OpenEpi (Version 3.01).[15] Means with SD and medians with range were used to describe continuous data and frequency tables were used for categorical variables. The injury incidence was expressed as the number of injuries per 1000 h of exposure. Incidence rate was calculated separately for games and practices, and for males and females. The Mid-P Exact test was used to compare incidence rates between subgroups. Injury incidences and incidence rate ratios (IRR) were expressed with 95% confidence interval (CI). A p value <0.05 was considered significant. Benjamini–Hochberg adjustments for p values were calculated to control false discovery rate arising from multiple comparisons problem. Critical value for a false discovery rate was set to 0.25.

3. Results

The baseline characteristics of the subjects, as well as exposure hours and number of injuries during the follow-up are presented in

Table 1
Demographic information, exposure time and number of acute time-loss injuries in female and male junior league players (n = 186).

	Female, n = 75	Male, n = 111
Age, y	16.1 (1.5)[a]	16.9 (1.3)[a]
Height, cm	166.5 (5.6)[a]	177.5 (164.5–199)[b]
Weight, kg	59.4 (45.5–80.0)[b]	68.3 (52.4–98.5)[b]
BMI	21.5 (17.8–27.2)[b]	21.7 (17.2–29.8)[b]
Menarche, no/yes	2/73	–
Playing experience, y	6.0 (2.5)[a]	8.7 (2.8)[a]
Total exposure, h	35 848[c]	34 095[c]
Game exposure, h	960[c]	1236[c]
Training exposure, h	34 888[c]	32 859[c]
Total number of injuries	86[d]	58[d]
Game related injuries	35[d]	24[d]
Training related injuries	51[d]	34[d]

[a]Results given as mean (± SD).
[b]Results given as median (range).
[c]Results given as total hours of exposure.
[d]Results given as total number of injuries for the subgroups.

Table 1. Total of 178 acute injuries were reported during the 3-year follow-up. Thirty-four of the reported injuries were excluded from the analyses, because they were not time-loss injuries (n = 4) or they had occurred in adult league games (n = 30). Fourteen female and three male participants had suffered 26 and 4 acute injuries, respectively, in adult league games during the follow-up. Altogether, 144 acute time-loss injuries were analyzed. Rates of injury in junior league athletes by type of exposure are presented in Table 2. Injury incidence was higher in games compared to practices (IRR 21.21, 95% CI 15.30–29.82, p < 0.001). Female players had significantly higher game injury rate and joint/ligament injury rate compared to males (Table 2).

Eighty-one percent of injuries affected the lower limb. The ankle was the most common site of injury (37%), followed by the knee (18%) and thigh (14%) (Table 2). Twenty-one ankle injuries and 17 knee injuries occurred in games. Injury incidences of ankle and knee injuries in junior league games was 9.56 (95% CI 5.49–13.63) and 7.74 (95% CI 4.08–11.41) per 1000 game hours, respectively. More than half (54%) of injuries involved joint or ligament (Table 2). Number of ankle and knee joint/ligament injuries was 52 and 21, respectively. Most common injured ligament structures were the lateral ligament complex of the ankle joint (n = 49) and the ACL of the knee (n = 8). All of the eight ACL injuries in the study occurred in female players.

Thirty-one muscle or tendon strains occurred and majority of them affected the posterior thigh (n = 9), anterior thigh (n = 8), and groin (n = 7). Tendon strains included one Achilles tendon rupture and one plantar fascia rupture. Contusions (n = 13) were most common in the knee (n = 5) and anterior or lateral thigh (n = 3). Nine fractures involved the toe (n = 3), coccyx (n = 2), wrist, rib, ankle, and fibula. Eight of the injuries were categorized as an undefined injury, due to unspecific diagnosis (eg. acute back injury). In addi-

Table 2
Number and incidence of acute time-loss injuries and incidence rate ratio for female and male floorball in junior league games.

	All players (n = 186)		Female players (n = 75)		Male players (n = 111)		IRR (95% CI)[e]	p Value	p Value[BH]
	n[a]	Incidence (95% CI)	n[a]	Incidence (95% CI)	n[a]	Incidence (95% CI)			
All injuries[b]	144	2.06 (1.72–2.39)	86	2.40 (1.89–2.91)	58	1.70 (1.26–2.14)	1.41 (1.01–1.98)	0.04	0.25
Game-related injuries[c]	59	26.87 (20.10–33.63)	35	36.46 (24.60–48.31)	24	19.42 (11.72–27.11)	1.88 (1.12–3.19)	0.02	0.17[††]
Training-related injuries[d]	85	1.25 (0.99–1.52)	51	1.46 (1.06–1.86)	34	1.03 (0.69–1.38)	1.41 (0.92–2.20)	0.12	0.42
Injury location[b]									
Ankle	53	0.76 (0.55–0.96)	32	0.89 (0.58–1.20)	21	0.62 (0.35–0.88)	1.45 (0.84–2.55)	0.19	0.42
Knee	26	0.37 (0.23–0.51)	16	0.45 (0.23–0.66)	10	0.29 (0.11–0.48)	1.52 (0.69–3.48)	0.30	0.44
Thigh	20	0.29 (0.16–0.41)	13	0.36 (0.17–0.56)	7	0.21 (0.05–0.36)	1.77 (0.71–4.72)	0.23	0.42
Lower back/sacrum	8	0.11 (0.04–0.19)	6	0.17 (0.03–0.30)	2	0.06 (0.00–0.14)	2.85 (0.60–20.54)	0.20	0.42
Hip/groin	8	0.11 (0.04–0.19)	5	0.14 (0.02–0.26)	3	0.09 (0.00–0.19)	1.59 (0.37–8.06)	0.55	0.65
Wrist	6	0.09 (0.02–0.15)	4	0.11 (0.00–0.22)	2	0.06 (0.00–0.14)	1.90 (0.34–14.85)	0.49	0.61
Head/face	5	0.07 (0.01–0.13)	3	0.08 (0.00–0.18)	2	0.06 (0.00–0.14)	1.43 (0.21–12.00)	0.73	0.79
Foot/toe	5	0.07 (0.01–0.13)	1	0.03 (0.00–0.08)	4	0.12 (0.00–0.23)	0.24 (0.01–1.89)	0.20	0.42
Lower leg/achilles	4	0.06 (0.00–0.11)	1	0.03 (0.00–0.08)	3	0.09 (0.00–0.19)	0.32 (0.01–2.97)	0.35	0.49
Shoulder	4	0.06 (0.00–0.11)	2	0.06 (0.00–0.13)	2	0.06 (0.00–0.14)	0.95 (0.10–9.14)	0.96	0.97
Neck/upper back	2	0.03 (0.00–0.07)	2	0.06 (0.00–0.13)	–	NA	NA	0.26	0.42
Abdomen/rib	2	0.03 (0.00–0.07)	1	0.03 (0.00–0.08)	1	0.03 (0.00–0.09)	0.95 (0.02–37.09)	0.97	0.97
Finger	1	0.01 (0.00–0.04)	–	NA	1	0.03 (0.00–0.09)	NA	0.49	0.61
Injury type[b]									
Joint/ligament	78	1.12 (0.87–1.36)	50	1.39 (1.01–1.78)	28	0.82 (0.52–1.13)	1.70 (1.07–2.73)	0.02	0.17[††]
Muscle/tendon	31	0.44 (0.29–0.69)	19	0.53 (0.29–0.77)	12	0.35 (0.15–0.55)	1.51 (0.73–3.20)	0.27	0.42
Contusion	13	0.19 (0.08–0.29)	6	0.17 (0.03–0.30)	7	0.21 (0.05–0.36)	0.82 (0.26–2.52)	0.72	0.79
Fracture/bone injury	9	0.13 (0.04–0.21)	2	0.06 (0.00–0.13)	7	0.21 (0.05–0.36)	0.27 (0.04–1.22)	0.09	0.42
Undefined[f]	8	0.11 (0.04–0.19)	6	0.17 (0.03–0.30)	2	0.06 (0.00–0.14)	2.85 (0.60–20.54)	0.20	0.42
Concussion	3	0.04 (0.00–0.09)	3	0.08 (0.00–0.18)	–	NA	NA	0.13	0.42
Eye injury	2	0.03 (0.00–0.07)	–	NA	2	0.06 (0.00–0.14)	NA	0.24	0.42
Specific injuries[b]									
ACL rupture[g]	8	0.11 (0.04–0.19)	8	0.22 (0.07–0.38)	–	NA	NA	0.01	0.17[††]
Lateral ankle sprain[h]	49	0.70 (0.50–0.90)	30	0.84 (0.54–1.14)	19	0.56 (0.31–0.81)	1.50 (0.85–2.71)	0.17	0.42

[a] Number of injuries in junior league games and team practices.
[b] Incidence is based on 1000 hours of total exposure (junior game + practice hours).
[c] Incidence is based on 1000 hours of junior game exposure.
[d] Incidence is based on 1000 hours of training exposure.
[e] Incidence rate ratio for female versus male floorball players. Significance level was < 0.05. NA = not available.
[f] Undefined back and neck injuries with unspecified diagnosis.
[g] Anterior cruciate ligament rupture of the knee.
[h] Injury of the lateral ligament complex of the ankle.
[BH] Benjamini-Hochberg adjusted p values for controlling False Discovery Rate of 0.25.
[††] Significant Benjamini–Hochberg adjusted p values.

Table 3
Severity of floorball injuries (n = 144) by body region, given as number of injuries.

Body region	Minimal (1–3 days)			Mild (4–7 days)			Moderate (8–28 days)			Severe (>28 days)			All injuries		
	Female	Male	All	Female	Male	All	Female	Male	All	Female	Male	All	Female	Male	All
Head/neck	2	–	2	–	–	–	2	–	2	–	2	2	4	2	6
Upper limbs	1	–	1	2	2	4	2	2	4	1	1	2	6	5	11
Spine/trunk	3	1	4	2	–	2	2	2	4	1	–	1	8	3	11
Lower limbs	11	8	19	19	17	36	18	11	29	20	12	32	68	48	116
All injuries	17	9	26	23	19	42	24	15	39	22	15	37	86	58	144

tion, three concussions and two eye injuries occurred among the players.

Direction chance/sudden stop was the most frequent injury situation (21% of all injuries), followed by collision/body contact with another player (19% of all injuries). Proportions of contact injuries, indirect contact injuries and noncontact injuries were 32%, 12%, and 56%, respectively. Seventy-seven percent of ankle ligament injuries and 86% of knee ligament injuries were noncontact/indirect contact injuries. All ACL injuries occurred without direct contact to the knee region: three of them as a result of an indirect contact (push to the upper body), two in sudden direction change, two in shooting, and one in running. Five ACL injuries occurred in junior games, and three in floorball practices. Two eye injuries occurred in games: one was caused by a stick, another by a collision with a wall bar. Players with eye injury did not wear protective eyewear when the injury occurred. Two concussions resulted from collision/body contact with another player while playing floorball, and one was caused by a hit of a medicine ball during conditioning training.

Seventeen percent of injuries were recurrent injuries: 20 players sustained 24 recurrent injuries. In 13 cases prior injury was sustained before the start of the study. Nine players out of 74 who completed more than 1 study year suffered recurrences (12 re-injuries) during their 2nd or 3rd follow-up year. The recurrent injuries included 23 ligament/joint injuries, and a muscle strain. Twenty out of 24 recurrent injuries were lateral ankle sprains, and the remaining four injuries included an ACL rupture, a meniscal tear, a shoulder subluxation, and a hamstring muscle strain. Twelve players suffered one recurrent ankle sprain, and four players had two recurrences. Eleven out of 20 recurrent ankle sprains were delayed recurrences, eight were late recurrences and one was early recurrence. Sixteen out of 20 recurrent ankle sprains were noncontact/indirect contact injuries, and 3 recurrent sprains affected braced ankles.

Severity of injuries is presented in Table 3. The most typical severe injuries involved the knee (n = 15) and ankle (n = 10). The most common type of severe injury was joint/ligament injury (n = 25), followed by muscle strain (n = 5). In addition, severe injuries included three fractures (toe, ankle, and fibula), two eye injuries (retinal ablation), an acute lower back injury, and lower limb contusion. Two eye injuries caused time-loss of 42 and 100 days.

The study cohort comprised 18 goalkeepers (5 females, 13 males). During the follow-up, five goalkeepers suffered from ten acute injuries: 3 of them occurred in junior games (2 noncontact knee injuries; concussion), 3 in floorball practices (hamstring rupture; noncontact ankle sprain; noncontact knee injury), and 4 in conditioning training (3 noncontact ankle sprains; low back injury). Goalkeepers' injuries in floorball practices and games occurred while saving the goal, whereas ankle sprains in conditioning training occurred in running exercises and a back injury in weight lifting.

Half of all injuries (51%) were diagnosed and treated by medical practitioners, while the remaining injuries were self-treated at home and the diagnosis was determined by the study physician (J.H.) during a telephone interview. Twenty-three percent of injuries were diagnosed by a specialist doctor in a private health care clinic, 17% were diagnosed at the Medical Center of the UKK Institute (J.P. or P.K.), 6% by a physician in a hospital, 3% by a physician in a public health care center, and 2% were diagnosed by other medical practitioners (physiotherapist or nurse). All ACL injuries were verified by magnetic resonance imaging (MRI).

4. Discussion

This is the first prospective study on epidemiology of acute floorball injuries in junior league players. Earlier studies have focused on describing injuries in adult top level floorball.[1–4] Our study found that the most frequently injured body parts in adolescent floorball players were the ankle, knee and thigh, and the most of the injuries affected joint/ligament structures. These findings are consistent with injury profile in adult floorball players.[1–4] The most significant finding of this prospective study was the very high rate of injuries in young female players. Compared to men, women had significantly higher rates of game and joint/ligament injuries.

It is noteworthy that in the present study including only adolescents, one fourth of injuries were severe, causing time-loss from sports more than 28 days. This is in clear contrast with findings from the previous floorball studies,[2–4] which showed that most of the injuries among adult players are minor. Eight ACL injuries occurred in this study and all of the affected players were women. Many previous studies have proven that females are more prone to knee injuries.[16–19] Further, it has been estimated that females have approximately 4–6 times higher risk for ACL tear than their male counterparts.[18]

In the current study, 68% of all injuries occurred without a direct contact to the injured body region. Eighty-six percent of knee ligament injuries and 77% of ankle ligament injuries occurred via noncontact/indirect contact mechanism. All the ACL ruptures occurred in noncontact/indirect contact situations. Griffin et al.[16] have pointed in their study that majority of ACL injuries (70%) takes place in noncontact situations. This indicates that intrinsic, person-related factors are of importance. Team ball sports have high rates of knee injuries in particular, most likely because players perform frequently rapid cutting maneuvers as well as jumps and landings. To avoid injurious forces in these fast sports movements, proper technique and movement control are needed.[13]

Number of recurrent ankle sprains was rather high among our junior players. Twenty out of 24 recurrent injuries were ankle sprains. According to Bahr & Bahr[20] athletes have an increased risk of recurrent injury during the first year after an ankle injury. Similar trend have been found in the risk of recurrent knee joint, hamstring and groin injuries.[21,22] Bracing and proprioceptive training have been shown to be effective in decreasing the risk of both first-time and recurrent ankle sprains,[23–27] but there is limited evidence on prevention of other types of recurrent injuries. However, in general many intervention studies have shown that prevention of sports injuries is possible by regular neuromuscular training.[12,28–31] Consequently, preventive training programs should be included in weekly and year-round training of these adolescent floorball players.

Two eye injuries occurred in the present study: one of them was caused by a stick and another by a collision with a wall bar. Even though the number of eye injuries was low, these severe injuries should be taken into consideration. Neither of these injured players wore protective eyewear when the injury occurred. Earlier studies have estimated that floorball is one of the high-risk sports concerning eye-injuries[8–10] and therefore the use of protective eyewear during floorball practices and games is crucial. Previous studies have shown that proper eye protectors can reduce the risk of eye injury by 90%.[32,33] Since 2008 protective eyewear has been required in the Finnish junior series among players whose year of birth is 1999 or later, but all participants of this study were born before 1999, thus use of eye protection was not mandatory for them.

Our study has several strengths. First, all the data was collected prospectively. Second, exposure time on team practices was collected individually and game exposure was based on actual playing time of each team. Third, accuracy of injury data collection was good, because communication with the participating teams was rather easy to carry out in the relatively small area (one city). However, our study also had some limitations. First, players' inconsistent follow-up time can be seen as a limitation. Female teams completed all three follow-up years, while male teams were involved only in one-year or two-year follow-ups. On the other hand, the total follow-up time was relatively similar in female and male teams. Also, we feel that alternating follow-up time was not a major problem, since all the reported injury rates were based on true exposure hours in practices and games.

Another limitation is that only half of the injuries were diagnosed by clinical examination. The remaining half was diagnosed by the study physician's (J.H) telephone interview. Thus, it was possible that precision in reporting injuries, such as the details of the injury type (structure) and injury mechanism, could remain somewhat uncertain. In addition, some minor injuries may have not been reported. Finally, the study cohort itself can be seen a limitation because the participants of the current study represented a relatively small proportion of the all young floorball players in Finland. Hence, some risk factors of injury, such as team habits and training conditions might be different in a larger youth floorball population.

5. Conclusions

The present study revealed that injury risk in adolescent floorball is considerable. The ankle, knee and thigh were the most commonly injured body parts in both sexes. Majority of the knee and ankle injuries occurred in noncontact/indirect contact circumstances, and concerning ankle sprains, notable was the high recurrence rate. Compared to men, the female players had significantly higher injury rate during games, and also the rate of joint and ligament injuries was significantly higher in women. Results of this study can be used to design prevention strategies to reduce injuries in adolescent floorball. This information is beneficial to athletic coaches, physical therapists, physicians, as well as athletes themselves.

Practical implications

- Preventive measures in adolescent floorball should focus on ankle and knee ligament injuries.
- Treatment, rehabilitation and return to sport after an injury should receive special attention to avoid recurrent injuries.
- Use of eye protection should be mandatory in floorball.

Acknowledgments

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ORIGINAL ARTICLE

WILEY

Association between lower extremity muscular strength and acute knee injuries in young team-sport athletes

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Abstract

The purpose of this study was to investigate LE muscular strength variables as potential risk factors for all and non-contact acute knee and ACL injuries in young athletes. A total of 188 young (≤21) male and 174 female basketball and floorball players participated in LE muscular strength tests and were followed up to 3 years. The strength test battery consisted of 1RM leg press, maximal concentric isokinetic (60°/s) quadriceps and hamstrings, and maximal isometric hip abductor strength. The outcomes were a new acute knee or ACL injury and a new acute non-contact knee or ACL injury. A total of 51 (17 in males and 34 in females) new acute knee injuries registered and 17 (one in males and 16 in females) of these were ACL injuries. In the adjusted Cox regression models, only lower maximal hip abduction strength (kg/kg) was significantly associated with an increased risk of all knee injuries in males (HR 1.80 [95% CI, 1.03-3.16] for 1 SD decrease in hip abduction). However, ROC curve analysis showed an area under the curve 0.66 revealing that maximal hip abduction strength test cannot be used as a screening tool for an acute knee injury in young male athletes.

KEYWORDS

injury, ligament injury risk, musculoskeletal system

1 | INTRODUCTION

Knee injuries are one of the most common types of injuries in young athletes.[1,2] Knee ligament sprains are common acute knee injuries[1] with a rupture of the anterior cruciate ligament (ACL) as it most serious outcome often leading to long absence from or termination of sports, high risk of re-injury, and early osteoarthritis.[3,4] Female athletes have higher risk of knee and ACL injuries than males.[1]

Most of the ACL injuries occur in non-contact situations such as landings, plant-and-cut movements, or decelerations.[5] Increased knee valgus loading with tibial internal and/or external rotation seems to be the primary mechanism of these injuries.[5,6] Proper neuromuscular control in terms of strength, coactivation, and recruitment of hamstring and quadriceps muscles is essential to maintain dynamic varus-valgus stability of the knee.[7] Decreased hamstring strength has shown to increase the estimated ACL-loading during anticipated sidestep cutting movements.[8] There is also evidence that impairments in trunk control are associated with knee and ACL injuries[9] and decreased hip abductor strength has shown to increase knee valgus angles in single leg squats and landings.[10,11] Thus, lower quadriceps, hamstrings, or hip strength may contribute to increased risk of knee and ACL injuries, but the results from the existing studies are conflicting and most of the studies mainly include adult athletes or focus on female athletes.[12-16] The role of lower extremity (LE) muscular strength as a risk factor for acute knee and ACL injuries is not conclusive.

Identifying factors that play a part in the occurrence of sport injuries is essential before planning injury prevention programs.[17] Maximal LE muscular strength is a modifiable risk factor, which can be easily assessed in clinical setting. It increases with age in young athletes, especially in males over the age of 14 compared to females.[18] However, only few studies have investigated the association between maximal LE muscular strength and acute knee or ACL injuries in young athletes. In a recent case-control study, lower maximal one-repetition barbell squat strength was associated with acute knee and ACL injuries in young female but not in male athletes.[19] In another case-control study, decreased hamstring-to-quadriceps (HQ) ratio was related to increased risk of non-contact ACL injuries in female high school and collegiate athletes.[14] However, a nested and matched case-control study[20] revealed no associations between knee or hip muscle strength and non-contact ACL injuries neither in male nor female high school and collegiate athletes.

To our knowledge, there are no previous prospective studies on the relationship between LE muscular strength and acute knee and ACL injuries in young athletes. The purpose of this study was to investigate selected LE muscular strength variables as potential risk factors for acute knee and ACL injuries in young male and female team-sport athletes. We hypothesized that lower maximal muscular strength increases the knee and ACL injury risk in this population.

2 | METHODS

2.1 | Study design and participants

This study is part of the Predictors of Lower Extremity Injuries in Team Sports (PROFITS) study.[21] The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Pirkanmaa Hospital District, Tampere, Finland (ETL-code R10169). The participants signed a written informed consent before entering the study (including parental consent for participants under the age of 18).

Junior-aged (≤21) basketball and floorball players were recruited from 9 basketball and 9 floorball teams from 6 sports clubs from Tampere city district. All players played at the two highest junior or adult league levels. Inclusion criteria were as follows: 21 years of age or younger, official team member, and free from injury at baseline. Athletes were considered injury-free if they did not report injuries at baseline questionnaire and they were able to fully participate in baseline tests. Altogether, 214 male (102 basketball and 112 floorball) players aged 16.1 ± 1.7 years (range, 13-20 years) and 189 female (107 basketball and 82 floorball) players aged 15.5 ± 2.0 years (range, 12-21 years) entered the study during the preseason (April-May) in 2011, 2012, or 2013. Each player completed a baseline questionnaire including questions about age, sex, starting age, previous injuries, and playing experience. Baseline measurements of standing height (cm) and weight (kg) were recorded. The strength tests were maximal one-repetition seated leg press strength, maximal concentric isokinetic quadriceps and hamstring strength (60°/s), and maximal isometric hip abductor strength. After baseline tests, injury registration continued until the end of April 2014. A total of 190 male and 178 female players completed the tests. Six (2 male and 4 female) players were excluded from the analyses, because they were not official members of the participating teams during the follow-up leading to a total of 188 male (93 basketball and 95 floorball) and 174 female (96 basketball and 78 floorball) players in the final analysis (Figure 1).

2.2 | Muscular strength tests

The muscular strength tests were part of a baseline test battery used to investigate potential anatomical, biomechanical, and neuromuscular risk factors for injuries. The complete test protocol with standardized warm-up procedures before each test is described elsewhere.[21]

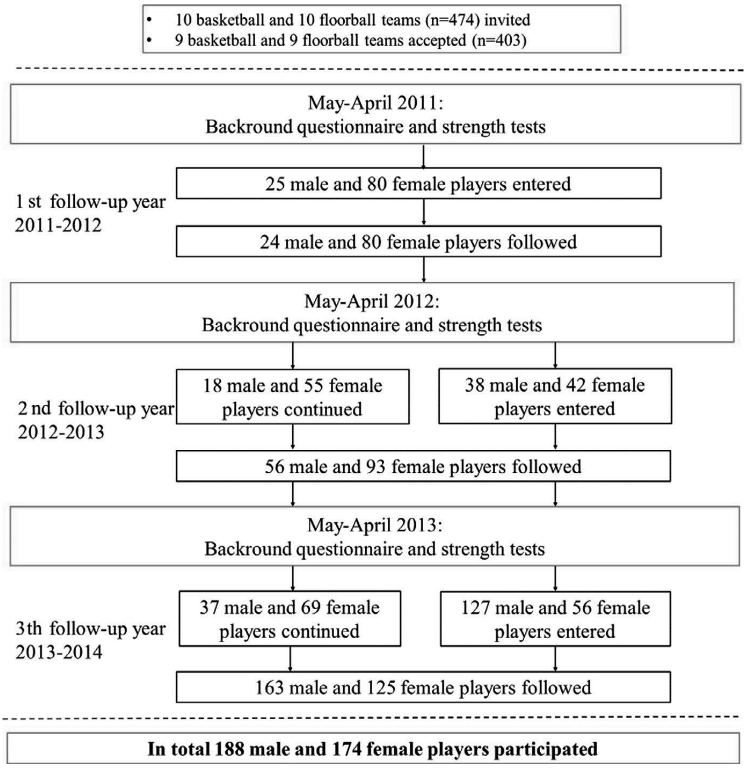

FIGURE 1 The flow of players

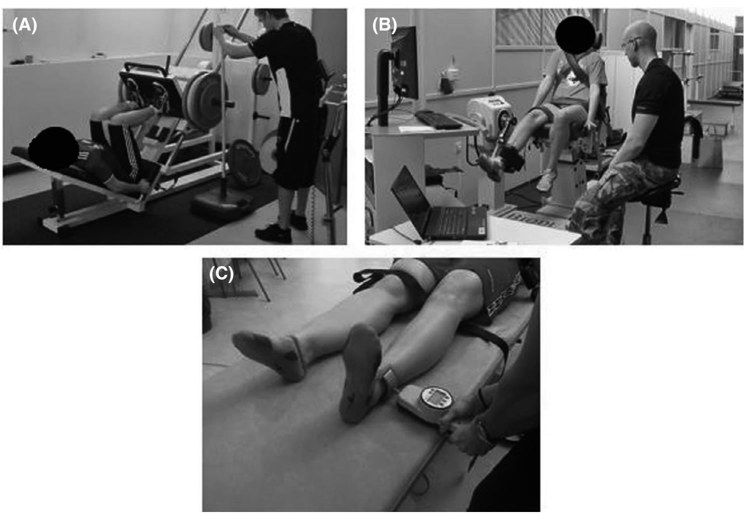

FIGURE 2 A, The measurement of maximal one-repetition seated leg press strength. B, the measurement of maximal concentric isokinetic quadriceps and hamstring strength; C, the measurement of maximal isometric hip abductor strength

2.2.1 | Maximal one-repetition leg press strength

A seated leg press machine (Technogym®) was used to measure a combined maximal extension strength of LE muscles. The distance between feet was 20 cm, and end of shoes was 10 cm above from the lowest end of the foot plate. The back of the seat was set on 30° angle relative to the floor. A vertical bar was placed at the point where the knees reached the target knee angle of 80° (Figure 2). The target knee angle was measured with a goniometer (HiRes, Baseline® Evaluation Instruments). The one-repetition maximum (1RM) leg press test protocol started with 80-150 kg depending on player's weight-bearing experience. At the starting point, player's legs were extended and the weights were then lowered until the knees form the correct angle and then returned at the starting position as hard as possible. After each successful trial, the weights were increased by maximum 30 kg after the first trials and by minimum 10 kg after the last trials for the next attempt. Recovery period between the attempts was 2 minutes and the test ends when one-repetition maximum was reached. Body mass normalized value was used in the analysis. Similar test has been proved to be reliable tool for measuring muscular strength regardless of sex.[22]

2.2.2 | Maximal isokinetic quadriceps and hamstring strength

Maximal isokinetic quadriceps and hamstring concentric strengths for both legs were measured at first study year (2011) in non-commercial dynamometer (Neuromuscular Research Center, University of Jyväskylä). At the second study year (2012), the dynamometer was replaced by Biodex Multi-Joint System Pro dynamometer (Biodex System 4, Biodex Medical Systems, Inc). A test procedure was the same either of the dynamometers used. The test range of motion was 90° through 15° of knee flexion with an angular velocity of 60°/s (Figure 2). A standardized test protocol[21] with gradually increasing intensity was performed, and the final test includes three repetitions with maximum power. The maximal strength was reported as peak torque (N·m) recorded, and body mass normalized value was used in the analysis. Strength difference between legs and HQ ratio was calculated. Isokinetic strength testing has been established as reliable tool for assessing muscular strength.[23]

To evaluate the reproducibility of measurements between the used two dynamometers, twelve 14- and 15-year-old male soccer players (24 legs) were tested with both dynamometers by different testers who collected the data. Intraclass correlation coefficient (ICC) value (3 k) was 0.81 (95% CI, 0.43-0.93) for isokinetic quadriceps and 0.79 (95% CI, 0.47-0.91) for isokinetic hamstring strength measurement meaning good test-retest reliability of the tests.

2.2.3 | Maximal hip abductor strength

Maximal isometric hip abductor strength (kg) was tested with a handheld dynamometer (Hydraulic Push-Pull Dynamometer, Baseline® Evaluation Instruments). The test was performed with the player lying legs extended in a supine position on bench. The pelvis and the contralateral thigh were fixed with a belt, and the player holds his or her arms across the chest during the test. The dynamometer was positioned approximately 2 cm proximal to the lateral ankle malleolus with the leg in neutral position and the foot in slight dorsiflexion (Figure 2). The muscle contraction was hold for approximately 2 seconds. After one test trial, the player performed two maximal contractions with a 10-second rest between the attempts. The better result was recorded, and body mass normalized value was used in the analysis. In addition, strength difference between legs was calculated. Similar procedure has showed to have excellent intra-tester reliability with measurement variation 3%[24] and acceptable inter-tester reliability with measurement variation 22%.[25]

2.3 | Injury and exposure registration

During a follow-up period (May 2011-April 2014), all acute knee injuries were registered with a structured questionnaire. Two study physicians were responsible for collecting the injury data. They contacted the teams once a week to check possible new injuries, and after each injury reported, the injured player was interviewed by telephone using the questionnaire. Injury definition was modified from definition by Fuller and colleagues.[26] An injury was recorded if the player was unable to fully participate in matches or training during the next 24 hours. Only injuries, which occurred in a teams' scheduled training sessions or matches, were included in this study. The injuries were classified as contact (ie, direct contact or strike to the involved knee) and non-contact (ie. no direct contact to the involved knee). All ACL injuries were verified by magnetic resonance imaging (MRI).

During the follow-up, the coach of each team recorded players' participation in trainings and matches. Player attendance in a training session (yes/no), duration of a training session (h), and attendance in each period of a match (yes/no) were recorded individually on a team diary. The diaries were returned after each follow-up month, and the individual monthly exposure time (h) was registered for all players.

2.4 | Statistical analysis

Descriptive data are presented as the mean ± standard deviation (SD) or the median and interquartile range (IQR) depending on the normality of distribution of variables. An independent-samples *t* test was used to compare group differences for normally distributed variables and the Mann-Whitney *U* test for non-normally distributed variables. Pearson's correlation coefficients were used to evaluate linear correlation between two variables. Injury incidences were calculated as the number of injuries per 1000 player-hours and reported with 95% CIs: ([Incidence rate − 1.96 * Standard error of incidence rate] * 1000 hours) to ([Incidence rate + 1.96 * Standard error of incidence rate] * 1000 hours). Results were calculated separately for male and female players and for all and non-contact knee and ACL injuries. Recurrent injuries were included in incidence calculations.

Cox regression models were used to analyze strength variables. The models were generated using the player as a unit of analysis or using the leg as a unit of analysis. The unit of analysis was defined according to strength variable representing either the characteristic of the player or of the leg.[27] The outcomes were a new acute knee or ACL injury and a new acute non-contact knee or ACL injury. The models were generated separately for males and females. Exposure time (h) from the start of the follow-up until the first injury or the end of the follow-up was included in the models. The exposure time of a month when an injury occurred was estimated by dividing the days from the beginning of the month to the injury date by all days of the month and then by multiplying the result by the registered total (playing and training) hours of the month. Sports club was included in all models as random effect and the leg in the models using it as the unit of analysis. Unadjusted and adjusted models with predefined adjustment factors were made for strength variables. The selected adjustment factors were previous acute knee injury and age as these might mostly influence to the risk of acute knee and ACL injuries.[17] These two adjustment factors were included in the models according to the amount of injuries in each model, using estimation of about 10 injuries needed per included variable (about 20 injuries, previous acute knee injury included, and about 30 injuries, also age included).[28] In the models using the player as the unit of analysis, previous injuries of ipsilateral or contralateral side were included, and in the models using the leg as a unit analysis, only injuries of ipsilateral side were included.

Cox hazard ratios (HRs) per 1 SD increase with 95% CIs were calculated for each strength variable. *P* value < .05 was considered significant. A receiver operating characteristic (ROC) curve analysis was calculated to assess the combined sensitivity and specificity of a test in cases where significant associations between the strength variable and the outcome were found. The test was defined as excellent (0.90-1.00), good (0.80-0.89), fair (0.70-0.79), poor (0.60-0.69), and fail (0.50-0.59). Statistical analyses were conducted in SPSS for Windows (v.20.0.0; SPSS), except the regression models, which were conducted in R (v3.1.2; R Foundation for Statistical Computing).

3 | RESULTS

3.1 | Baseline characteristics

Complete data were obtained from 188 (88%) male (93 basketball and 95 floorball) and 174 (92%) female (96 basketball and 78 floorball) players. As seen in Table 1, both male and female floorball players were significantly older

TABLE 1 Demographic data, exposure times an injury history in male (n = 188) and female (n = 174) players

	All (n = 188)	Basketball (n = 93)	Floorball (n = 95)	*P*-value	All (n = 174)	Basketball (n = 96)	Floorball (n = 78)	*P*-value
Age (y)[a]	16.0 ± 1.6	15.2 ± 1.6	16.8 ± 1.2	<.001	15.4 ± 2.0	14.6 ± 1.6	16.5 ± 1.9	<.001
Height (cm)[b]	178.6 ± 8.1	179.0 ± 9.6	178.2 ± 6.3	.49	167.4 ± 6.2	168.2 ± 6.4	166.5 ± 5.7	.08
Weight (kg)[b]	69.2 ± 10.9	68.6 ± 13.0	69.8 ± 8.3	.44	61.0 ± 8.6	61.0 ± 9.5	61.1 ± 7.3	.86
BMI, (kg/m^2)[b]	21.6 ± 2.7	21.3 ± 3.0	22.0 ± 2.3	.04	21.7 ± 2.7	21.5 ± 2.8	22.0 ± 2.5	.24
Playing experience (y)[b]	8.1 ± 3.1	7.4 ± 3.2	8.8 ± 2.8	.001	6.3 ± 2.5	6.4 ± 2.5	6.2 ± 2.5	.43
Match exposure (h)[c]	10.4 (10.0)	8.0 (6.3)	13.3 (8.6)	<.001	10.1 (16.4)	7.3 (8.8)	19.9 (25.5)	<.001
Training exposure (h)[c]	288.2 (228.8)	294.7 (178.5)	284.4 (276.8)	.53	252.0 (342.9)	203.3 (123.4)	478.6 (424.6)	<.001
Total exposure (h)[c]	298.9 (238.5)	300.0 (181.8)	297.8 (279.7)	.44	258.9 (365.1)	214.1 (124.6)	500.6 (456.7)	<.001
Previous acute knee injury (n)[d]	43	26	17	.10	43	18	25	.04
Previous ACL injury (n)[d]	7	4	3	.68	7	2	5	.15

[a]Age at the start of the follow-up. Values are presented as mean ± SD.

[b]Values are presented as mean ± SD.

[c]Values are presented as median (IQR).

[d]Values are presented as total number of injuries.

compared with basketball players. Male floorball players had also higher BMI. Male floorball players had significantly more playing hours and female floorball players also training hours than their basketball counterparts. In addition, female floorball players had significantly more previous acute knee injuries than basketball players. The mean follow-up periods during the three study years were 1.3 ± 0.6 and 1.7 ± 0.6 years in males and females, respectively.

3.2 | Injury characteristics

A total of 17 male (8 basketball and 9 floorball) and 29 female (9 basketball and 20 floorball) players sustained a new acute knee injury during the study. Five of these female players had both knees injured, and thus, 34 new knee injuries occurred in females. Two male and three female players had a re-injury to the same knee. An overall knee injury incidence for males and females was 0.3 (95% CI, 0.2-0.4) and 0.6 (95% CI, 0.4-0.8) per 1000 player-hours, respectively. Male players were on average 17.1 ± 1.3 (16.3 ± 1.0 in basketball and 17.9 ± 1.1 in floorball) and female players 16.5 ± 2.5 (14.1 ± 1.2 in basketball and 17.6 ± 2.2 in floorball) years at the time of first knee injury. Apart from ACL injuries, there were 5 contusions, 5 joint or ligament sprains, 3 meniscal lesions, 1 patellar dislocation, 1 intra-articular fracture and 1 unspecified injury in males and 7 contusions, 5 joint or ligament sprains, 1 meniscal lesion, and 5 unspecified injuries in females.

A new non-contact knee injury was registered in 9 male (7 basketball and 2 floorball) and 25 female (7 basketball and 18 floorball) players. Two females had both knees injured, yielding 27 new non-contact knee injuries in females. One male and three females had a re-injury to the same knee. The incidence for non-contact knee injury for males and females was 0.2 (95% CI, 0.1-0.3) and 0.5 (95% CI, 0.3-0.6) per 1000 player-hours, respectively.

Fifteen female (3 basketball and 12 floorball) players sustained a new ACL injury. One female player had both knees injured, and thus, 16 new ACL injuries occurred in females. Fifteen of these 16 new ACL injuries in females occurred in non-contact situations. In addition, one female player had a re-injury to the same knee in a non-contact situation. An overall and non-contact ACL injury incidence was 0.3 injuries per 1000 player-hours (95% CI, 0.1-0.4) in females. Only one male player had an ACL injury (occurred in a non-contact situation) during the study period, and thus, incidence rates were not calculated and the risk factor analysis not made for male ACL injuries.

3.3 | Unadjusted group differences

Unadjusted group comparisons revealed that male players who suffered any knee injury were 10% (3.20 ± 0.62 vs 2.91 ± 0.55; $P = .04$) and female players 8% (2.56 ± 0.43 vs 2.37 ± 0.38; $P = .02$) stronger than uninjured players measured by 1RM leg press strength (kg/kg) (Appendix S1 and S2). Similarly, in males who suffered a non-contact knee injury, 1RM leg press strength was 16% (3.36 ± 0.48 vs 2.91 ± 0.56; $P = .04$) and in females 10% (2.61 ± 0.41 vs 2.37 ± 0.38; $P = .04$) greater compared to uninjured players (Appendix S1 and S2). Also, in males who had a non-contact knee injury, maximal isokinetic quadriceps strength (N·m/kg) was 11% greater in injured legs (2.86 ± 0.42) compared to uninjured legs (2.57 ± 0.42, $P = .046$) (Appendix S1). Moreover, maximal hip abduction strength (kg/kg) was significantly lower in males who had any (0.19 ± 0.05 vs 0.22 ± 0.04; $P = .02$) or a non-contact (0.19 ± 0.06 vs 0.22 ± 0.04; $P = .02$) knee injury compared to uninjured players (Appendix S1).

In female players who suffered any ACL injury, 1RM leg press strength (2.60 ± 0.28 vs 2.39 ± 0.39; $P = .048$) and between-leg difference in hip abduction strength (kg) [2.00 (1.00) vs 1.00 (2.00); $P = .03$] were significantly greater compared to uninjured players (Appendix S3).

3.4 | Unadjusted risk factor analyses

In unadjusted Cox-regression models, the greater 1RM leg press strength was associated with an increased risk of non-contact knee injuries in males and females (HR for 1 SD increase, 2.30 [95% CI, 1.14-4.65]; $P = .02$ and 1.52 [95% CI, 1.04-2.21]; $P = .03$, respectively) (Table 2). There was a moderate correlation ($r = .48$, $P < .001$) between players' age and 1RM leg press strength in males and weak correlation ($r = .31$, $P < .001$) in females. Only very weak correlation existed between players' playing and practicing time and 1RM leg press strength in both males ($r = .15$, $P = .04$) and females ($r = .19$, $P = .01$). In males, the greater between-leg difference in isokinetic quadriceps strengths (N·m) was also associated with an increased risk of non-contact knee injury (HR for 1 SD increase, 1.85 [95% CI, 1.02-3.35]; $P = .04$). None of the strength variables were statistically significantly associated with female ACL injuries in unadjusted models (Table 3).

3.5 | Adjusted risk factor analyses

Due to the low amount of non-contact knee injuries in males, adjusted risk factor analyses were not made for these male injuries. In females, the trend in 1RM leg press strength was similar as in the unadjusted models, but the observed difference was not statistically significant (HR for 1 SD increase 1.48 [95% CI, 0.97-2.26]; $P = .07$). In the adjusted models, only lower maximal hip abduction strength was associated with an increased risk of all knee injuries in males (HR 1.80 [95% CI, 1.03-3.16]; $P = .04$ for 1 SD decrease in hip

TABLE 2 Unadjusted and adjusted HR (per 1 SD increase) with 95% CIs for strength variables for knee injuries in males and females[a]

	Male			Female			
	All knee injuries (n = 17)		Non-contact knee injuries (n = 9)	All knee injuries (n = 34)		Non-contact knee injuries (n = 27)	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Player as a unit of analysis							
Leg press (kg/kg)[b]	1.52 (0.92-2.49)	1.42 (0.79-2.54)[d]	**2.30 (1.14-4.65)**	1.35 (0.96-1.90)	1.23 (0.83-1.84)[e]	**1.52 (1.04-2.21)**	1.48 (0.97-2.26)[e]
Quadriceps between- leg differences (Nm)[c]	1.35 (0.85-2.15)	1.13 (0.72-1.77)[d]	**1.85 (1.02-3.35)**	0.72 (0.44-1.17)	0.74 (0.46-1.19)[e]	0.58 (0.33-1.04)	0.58 (0.34-1.01)[e]
Hamstring between- leg difference (Nm)[c]	1.15 (0.75-1.76)	1.14 (0.69-1.86)[d]	1.13 (0.63-2.03)	1.03 (0.72-1.48)	1.03 (0.69-1.53)[e]	0,98 (0.65-1.46)	0.95 (0.61-1.47)[e]
Hip abduction between-leg differences (kg)[c]	1.25 (0.81-1.93)	1.04 (0.69-1.57)[d]	1.06 (0.58-1.93)	1.02 (0.70-1.48)	1.08 (0.74-1.57)[e]	1.11 (0.76-1.61)	1.20 (0.82-1.76)[e]
Leg as a unit of analysis							
Quadriceps (Nm/kg)[b]	1.51 (0.92-2.49)	1.50 (0.88-2.57)[d]	2.00 (0.96-4.15)	0.96 (0.68-1.35)	0.92 (0.63-1.33)[e]	1.01 (0.69-1.48)	0.99 (0.66-1.49)[e]
Hamstrings (Nm/kg)[b]	1.20 (0.72-2.01)	1.04 (0.63-1.72)[d]	1.41 (0.68-2.90)	0.78 (0.54-1.13)	0.73 (0.49-1.09)[e]	0.87 (0.58-1.31)	0.83 (0.53-1.31)[e]
HQ ratio (%)	0.80 (0.49-1.33)	0.72 (0.42-1.24)[d]	0.68 (0.31-1.46)	0.75 (0.53-1.07)	0.76 (0.53-1.09)[e]	0.82 (0.55-1.22)	0.81 (0.54-1.22)[e]
Hip abduction (kg/kg)[b]	0.56 (0.31-1.01)	**0.56 (0.32-0.97)**[d]	0.65 (0.29-1.47)	1.01 (0.72-1.44)	1.04 (0.74-1.46)[e]	0.98 (0.66-1.46)	1.00 (0.68-1.48)[e]

[a]Values in parentheses are 95% CIs. Significant results are marked in bold. HQ ratio, hamstring to quadriceps ratio.

[b]Body mass normalized values.

[c]Difference between stronger and weaker leg.

[d]Adjustment factor: previous acute knee injury.

[e]Adjustment factors: previous acute knee injury and age.

TABLE 3 Unadjusted and adjusted HR (per 1 SD increase) with 95% CIs for strength variables for ACL injuries in females[a]

	All ACL injuries (n = 17)		Non-contact ACL injuries (n = 16)	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Player as a unit of analysis				
Leg press (kg/kg)[b]	1.57 (0.90-2.71)	1.51 (0.84-2.73)[d]	1.51 (0.86-2.65)	1.44 (0.78-2.64)[d]
Quadriceps between- leg differences (Nm)[c]	0.79 (0.42-1.47)	0.79 (0.44-1.40)[d]	0.75 (0.38-1.46)	0.75 (0.40-1.39)[d]
Hamstring between-leg difference (Nm)[c]	1.34 (0.84-2.15)	1.35 (0.82-2.22)[d]	1.25 (0.76-2.04)	1.25 (0.74-2.12)[d]
Hip abduction between-leg differences (kg)[c]	1.27 (0.86-1.87)	1.35 (0.91-1.99)[d]	1.27 (0.85-1.91)	1.36 (0.90-2.06)[d]
Leg as a unit of analysis				
Quadriceps (Nm/kg)[b]	1.06 (0.64-1.76)	1.11 (0.66-1.87)[d]	1.00 (0.59-1.69)	1.05 (0.61-1.80)[d]
Hamstrings (Nm/kg)[b]	0.94 (0.56-1.57)	0.99 (0.59-1.66)[d]	0.98 (0.58-1.66)	1.03 (0.60-1.76)[d]
HQ ratio (%)	0.89 (0.53-1.48)	0.90 (0.54-1.51)[d]	0.99 (0.57-1.70)	1.01 (0.59-1.74)[d]
Hip abduction (kg/kg)[b]	0.92 (0.56-1.54)	0.96 (0.58-1.61)[d]	0.88 (0.52-1.50)	0.92 (0.54-1.57)[d]

[a]Values in parentheses are 95% CIs. Significant results are marked in bold. HQ ratio, hamstring to quadriceps ratio.

[b]Body mass normalized values.

[c]Difference between stronger and weaker leg.

[d]Adjustment factor: previous acute knee injury.

abduction) (Table 2). However, ROC curve analysis for hip abduction strength test in males showed an area under the curve 0.66, indicating poor combined sensitivity and specificity of the test (sensitivity of the test 65% and specificity 62%). In females, none of the strength variables were statistically significantly associated with knee or ACL injuries in the adjusted models (Tables 2 and 3).

4 | DISCUSSION

The purpose of this prospective study was to investigate the association between selected LE muscular strength variables as potential risk factors for all or non-contact acute knee and ACL injuries in young male and female team-sport athletes. The main finding was that lower maximal hip abduction strength was associated with increased risk of all acute knee injuries in young male basketball and floorball players, when adjusted for previous acute knee injury. Secondly, we found that none of the measured strength variables were associated with all or non-contact acute knee or ACL injury risk in young female players.

The findings concerning female players are supported by two prospective Norwegian studies, investigating the same strength variables: 1RM leg press strength, maximal isokinetic concentric hamstring and quadriceps strength at angular velocity of 60°/s, HQ ratio, and maximal hip abduction strength measured with handheld dynamometer.[15,16] Nilstad et al[15] studied a cohort of elite female soccer players and found no associations between any of these strength variables and all knee injuries. Steffen et al[16] studied partly the same elite female soccer player cohort as Nilstad and colleagues[15] and in addition to them, elite handball players, and reported either no associations between these strength variables and non-contact ACL injuries. Although the players in the present study were considerably younger (15.4 years on average compared to 20.9 and 21.5 years in the Norwegian studies) and played mainly in junior-league matches, the selected muscular strength variables did not seem of significance alone in knee injury risk in females. However, separation between acute and overuse knee injuries was not made in Nilstad and others[15] study making direct comparisons to our study unreliable.

Also, Vacek and study group[20] found in a nested and matched case-control study no associations between maximal isokinetic quadriceps, hamstring or isometric hip abduction strength, and non-contact ACL injuries neither in female nor male high school and college athletes. ACL-injured players were 14-23 years with 75% of them between the ages of 15-20 years, but the measurement procedures, although not described in detail, were different from ours. Vacek and colleagues[20] measured quadriceps and hamstring strength with the knee at 15° and 30° flexion and hip abduction strength with a custom stabilization cage interfaced with a load sensor and force gauge.

A seated leg press, as a closed kinetic chain and multi-joint movement, was used to assess combined LE extension strength in the present study. It activates powerful LE muscles like gluteus maximus, quadriceps, hamstrings, and gastrocnemius and have similarities to many athletic movements such as running and jumping.[29,30] Interestingly, the greater 1RM leg press strength was associated with increased risk of non-contact knee injuries in both male and female players in the unadjusted Cox regression models. It could be assumed that older players are stronger and they practice and play more even in adult league teams thus being more time at risk to get an injury. Very weak to moderate correlations between players' age or playing and practicing time and 1RM leg press strength indicate that age and exposure time alone are not sufficient enough to explain this finding. However, stronger players in this study might have been more mature and skilled otherwise. Strong players may also be able to run and change direction faster leading to greater mechanical forces, and in this way, the injury risk may increase. In addition, being strong does not necessarily mean that a player has a proper landing and direction change technique. Poor technique combined with greater muscle mass and higher speed may increase ligament loading and injury risk in strong players compared to weaker lightweight players.

In contrast of our finding, Ryman Augustsson and Ageberg[19] studied also a cohort of young male and female athletes (aged 15-19) and found that lower 1RM barbell squat strength was associated with increased risk of all acute knee injuries in females but not in males. However, due to a greater quadriceps and hamstring activity generated, tibiofemoral and patellofemoral compressive forces have shown to be generally greater in the squat than in the leg press exercise and this may provide enhanced knee stability during the squat exercise.[30] Thus, despite the great 1RM leg press strength, an athlete may not have such great knee stability and this may reflect to the increased risk especially for non-contact knee injuries.

Increased hamstring force during the knee flexion phase has shown to decrease relative strain on the ACL,[31] and maximal isokinetic concentric hamstring strength has shown to remain steady with increasing maturational age in young female athletes while increasing in male athletes.[32] Thus, it could be assumed that low hamstring strength or HQ ratio might be a risk factor for acute knee and ACL injuries especially in young female athletes. However, we found no associations between isokinetic concentric quadriceps or hamstring strength or HQ ratio with all or non-contact acute knee injuries in males and females, and additionally, with all or non-contact ACL injuries in females. In line with our findings, Uhorchak and colleagues[33] reported no associations between maximal concentric or eccentric isokinetic strength at angular velocity of 60°/s and non-contact ACL injuries in a group of male and female military academy cadets in a 4-year prospective study. However, although the military cadets were relatively similar age (18.4 years on average compared to 15.8 years in our study) and participated in different sports and physical activities, the cadets' likelihood to get an acute knee injury may not necessarily be comparable with team-sport players in our study.

Myer et al[14] showed in a matched case-control study that female high school and collegiate soccer and basketball players who suffered a non-contact ACL injury had a combination of decreased maximal concentric isokinetic hamstring strength but not quadriceps strength compared to male controls. On the other hand, female controls who did not suffer a non-contact ACL injury had decreased quadriceps but not hamstring strength compared to male controls, indicating that low HQ ratio may be the risk factor for non-contact ACL injuries in females. Although not mentioned, the female players in Myer and others[14] study could assume to be young and nearly similar age compared to the players in our study. In contrast, they measured maximal isokinetic concentric hamstring and quadriceps strength at much higher angular velocity of 300°/s. High angular velocities in isokinetic strength measurements can be speculated to correspond better to real injury situations in trainings and matches. However, the data from video analysis of ACL injury situations have showed that ACL injuries occur very fast, on average 40 ms after initial ground contact.[6] Thus, it is unlikely that the higher angular velocity in isokinetic strength tests explains the different findings in female players.

Increased hip abduction strength is thought to decrease knee loading and injury risk by counterbalancing hip adduction motion and subsequent knee valgus and abduction loads associated with acute knee and ACL injuries in female athletes.[11,34] We found no association between maximal hip abduction strength and all or non-contact acute knee or ACL injuries in young females, while in young males lower maximal hip abduction strength increased the risk for all acute knee injuries in the adjusted Cox regression model. The reasons behind this finding are unclear. On the bases of the fact that maximal quadriceps and hamstring strength increases more in male athletes compared to females from ages 14 to 17 years,[18] maximal hip abduction strength may also increase greatly in male athletes in this age group. Thus, young male athletes, who have weak hip abductors, could also have an increased risk to knee valgus and abduction loads similar to female athletes[34] leading to the increased risk of acute knee injuries. However, the maximal hip abduction strength test we used had a poor combined sensitivity and specificity in the ROC curve analysis making it usage as a screening tool for an acute knee injury questionably.

Low hip abduction strength and hip external rotation strength have been previously found to associate with LE[35] and ACL[13] injuries in female and male athletes. Leetun et al[35] studied prospectively male and female varsity intercollegiate basketball players and cross-country athletes and found that both male and female players who sustain any back or LE injury were significantly weaker in hip abduction and external rotation compared to uninjured athletes. On the other hand, in Leetun and colleagues study,[35] only 23% of injuries were knee injuries and only hip external rotation strength was the significant predictor of injury risk based on logistic regression analysis. Khayambashi et al[13] found in a prospective case-control study that decreased hip abduction and external rotation strength increased the risk of non-contact ACL injury in a group of male (on average 21.5 years) and female (on average 20.9 years) team-sport athletes. Although the data were not presented separately for males and females, it is noticeable that the majority of the athletes and ACL-injured players in Khayambashi and others[13] study were males, indicating that lower hip strength, in line with our study, increases the risk for acute knee and ACL injuries especially in males. In addition, this finding seems to be independent of players' age and maturity because our players were considerably younger. Although we found no associations between maximal hip abduction strength and non-contact knee injuries in males, this can purely be a result of the inadequate power of our study.

Although we found no association between LE muscular strength variables and the risk of acute knee or ACL injuries in young female athletes, it does not mean that strength exercises should be taken out of injury prevention programs in this group of athletes. It should be noticed that we measured maximal muscular strength, while in neuromuscular injury prevention programs, muscular strength training usually contains exercises with no additional weights concentrating on proper technique with gradually increasing volume and intensity.[36] A neuromuscular warm-up program including bodyweight strength exercises has shown to be effective in the prevention of acute knee and ACL injuries in young female soccer players.[37] In addition, lower maximal quadriceps, hamstrings, and hip external rotational strength are reported to increase the risk of overuse knee injuries in young female soccer players,[38] and an exercise program including strength training has shown to decrease the risk of anterior knee pain in male and female military recruits.[39] The mechanisms how strength training works are thought to be both direct (strengthening the certain muscles) and indirect (strength training-related effect to improved coordination, enhanced techniques in playing situations, strengthening adjacent tissues, and better psychological perception of high-risk situations).[36] Knee and ACL injury prevention programs including muscular strength exercises are available for young athletes,[37] and they are recommended to be included in regular training.

This study had several strengths including the relatively long follow-up, large sample size, and low dropout rate. In addition, prospectively collected injury and exposure data enabled the use of Cox regression analyses as the exact injury date and exposure time of each player were known. Moreover, the muscular strength variables were measured in this study with standard and simple procedures easy to use in clinical practice.

This study also had limitations. Only maximal muscular strength was measured in isokinetic quadriceps and hamstring strength testing. Maximal strength may provide limited information about the muscle performance during the full range of knee motion. The largest quadriceps strength deficits have been established at knee flexion angles <40° after ACL injury.[40] In addition, maximal isokinetic quadriceps and hamstring strength were measured in this study only with an angular velocity of 60°/s. It is obvious that much higher angular velocities are involved in knee movement patterns in ball sports. Maximal hip abduction strength could have been measured also with the hip in flexion because in real injury situations the hip is usually in flexion rather than in extension. Also, despite the 3-year follow-up, the prevalences of knee and ACL injuries were relatively low limiting the statistical power of the study. Thus, we might not detect other than rather strong risk factors[27] and had to limit the amount of adjustment factors to maintain validity of the Cox regression analyses.[28]

In conclusion, our 3-year prospective study showed that lower maximal hip abduction strength is associated with increased risk of all acute knee injuries in young male team-sport athletes. However, according to the ROC curve analysis, this hip abduction strength test is a poor injury screening test for these athletes. Thus, maximal LE muscular strength as measured in the present study cannot be used as a screening tool for an acute knee injury in young male athletes.

5 | PERSPECTIVES

The role of LE muscular strength concerning knee and ACL injuries is controversial, and the study results concerning youth athletes are sparse. The purpose of this prospective study was to investigate the association between selected lower extremity muscular strength variables as potential risk factors for all or non-contact acute knee and ACL injuries in young male and female team-sport athletes.

Although we found that lower maximal hip abduction strength was significantly associated with increased risk of acute knee injuries in young male athletes, maximal hip abduction strength test could not be used as an injury screening tool for these athletes. Additionally, this study gave evidence that great maximal LE extension strength could, in fact, increase the risk of acute non-contact knee injuries in young athletes. None of the strength risk factors were associated with all or non-contact acute knee or ACL injuries in young female athletes.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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Association between lower extremity muscle strength and acute ankle injury in youth team-sports athletes

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ABSTRACT

Objectives: To investigate lower extremity muscle strength as risk factor for an acute ankle injury in youth athletes.
Design: Cohort study.
Setting: Basketball and floorball clubs.
Participants: 188 youth (≤21) male and 174 female athletes.
Main outcome measures: 1RM leg press, maximal concentric isokinetic quadriceps and hamstrings as well as maximal isometric hip abductor strength were measured and athletes were followed for an acute ankle injury up to three years. Cox regression models were used in statistical analyses.
Results: In males, greater 1RM leg press and maximal quadriceps strength increased the risk of any type of acute ankle injury (Hazard ratio [HR] for 1 SD increase, 1.63 [95% CI, 1.12–2.39] and 1.43 [95% CI, 1.01–2.01], respectively). In females, greater 1RM leg press and difference between legs in hip abduction strength increased the risk of acute non-contact ankle injury (HR for 1 SD increase, 1.44 [95% CI, 1.03–2.02] and 1.44 [95% CI, 1.03–2.00], respectively). However, ROC curve analyses showed AUC:s of 0.57–0.64 indicating "fail" to "poor" combined sensitivity and specifity of these tests.
Conclusion: Greater strength in both sexes along with asymmetry in hip abductor strength in females increased the risk of acute ankle injury.

1. Introduction

Incidence of ankle injury is high in youth team sports (Borowski, Yard, Fields, & Comstock, 2008; Emery, Carolyn A., Meeuwisse, & Hartmann, 2005; Olsen, O-E, Myklebust, Engebretsen, & Bahr, 2006; Powell & Barber-Foss, 2000). Lateral ankle sprain is observed most frequently (Sankey, Brooks, Kemp, & Haddad, 2008; Starkey, 2000; Woods, Hawkins, Hulse, & Hodson, 2003a). Ankle sprain can lead to a marked loss of practicing and playing time (Cloke, Spencer, Hodson, & Deehan, 2009) and often evolve persistent pain, weakness and chronic instability possibly resulting in lower sport activity levels or even change of sports (Anandacoomarasamy & Barnsley, 2005).

Identifying risk factors that are modifiable and clinically easy to test are essential before planning injury prevention programs (Bahr & Krosshaug, 2005). The role of lower extremity (LE) muscle strength as a risk factor for sport injury is controversial. Lower quadriceps and hamstrings strength or strength imbalances

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between these muscles have shown to increase the risk of anterior cruciate ligament injury and hamstring strain (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008; Myer et al., 2009; Soderman, Alfredson, Pietila, & Werner, 2001) although contrary results also exist (Bennell et al., 1998; Uhorchak et al., 2003). In our previously published study, lower hip abduction strength increased the risk of acute knee injury in youth male athletes (Hietamo et al., 2020).

There are several studies investigating ankle dorsiflexion, plantar flexion, inversion, eversion, dorsiflexion and plantar flexion strength as well as strength ratios between these as risk factors for ankle injury (Beynnon, Renstrom, Alosa, Baumhauer, & Vacek, 2001; Wang, Chen, Shiang, Jan, & Lin, 2006; Willems, T. M. et al., 2005; Willems, Tine Marieke et al., 2005). However, based on kinetic chain theories, impairments of proximal core and hip muscle function are suggested to increase the likelihood of uncontrolled joint displacements distally and occurrence of distal LE injury (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Willson, Dougherty, Ireland, & Davis, 2005). Lower hip abduction strength has found to associate with chronic ankle sprains (Friel, McLean, Myers, & Caceres, 2006), but in another study, no association between hip muscle strength and the risk of non-contact lateral ankle sprain was reported in high school athletes (McHugh, Tyler, Tetro, Mullaney, & Nicholas, 2006). In addition, alterations in knee kinematics in jump landing task have found in subjects with chronic ankle instability (Gribble & Robinson, 2009) and neuromuscular training including quadriceps and hamstrings strengthening exercises have shown to decrease the risk of acute ankle injury in youth athletes (Emery, C. A. & Meeuwisse, 2010; Olsen, Odd-Egil, Myklebust, Engebretsen, Holme, & Bahr, 2005). Therefore, lower quadriceps and hamstrings strength may also be considered as risk factors for acute ankle injury.

The purpose of this study was thus to investigate selected LE muscle strength variables as potential risk factors for an acute ankle injury in youth male and female team-sport athletes. We hypothesized that lower muscle strength increases the risk of these injuries.

2. Methods

2.1. Study design and participants

This study is part of the Predictors of Lower Extremity Injuries in Team Sports (PROFITS) study (Pasanen et al., 2015). The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Pirkanmaa Hospital District, Tampere, Finland (ETL-code R10169). The participants signed a written informed consent before entering the study (including parental consent for participants under the age of 18).

Junior-aged (≤21 yrs) basketball and floorball athletes were recruited from 9 basketball and 9 floorball teams from 6 sports clubs from Tampere city district. All athletes played at the two highest junior or adult league levels. Altogether 214 male (102 basketball and 112 floorball) and 189 female (107 basketball and 82 floorball) athletes entered the study during the preseason (April–May) in 2011, 2012 or 2013. Each athlete completed a baseline questionnaire including questions about age, sex, previous injuries and playing level. Standing height (cm) and body mass (kg) were recorded and muscle strength tests performed. After baseline tests, injury registration continued until the end of April 2014. Twenty-four male and 11 female athletes were excluded due to ongoing injury. Athletes were considered as injured if they report injuries at baseline questionnaire or were not able to fully participate in muscle strength tests. In addition, 2 male and 4 female athletes were excluded, because they were not official members of the teams leading to a total of 188 (88%) male and 174 (92%) female athletes in the final analysis (Fig. 1). The demographic data and ankle injury history of athletes are presented in (Table 1).

2.2. Muscle strength tests

The muscle strength tests were part of a baseline test battery used to investigate potential anatomical, biomechanical and neuromuscular risk factors for injuries. The complete test protocol with standardized warm-up procedures before each test is described elsewhere (Pasanen et al., 2015).

2.2.1. Maximal one-repetition leg press strength

A seated leg press machine (Technogym®, Gambettola, Italy) was used to measure a combined maximal extension strength of LE muscles. The distance between feet was 20 cm and end of shoes were 10 cm above from the lowest end of the foot plate. The back of the seat was set on 30° angle relative to the floor. A vertical bar was placed at the point where the knees reached the target knee angle of 80° (Fig. 2). The target knee angle was measured with a goniometer (HiRes, Baseline® Evaluation Instruments, White Plains, NY, USA). A standardized warm-up protocol consisted three sets with gradually increasing weights (Pasanen et al., 2015). The one-repetition maximum (1RM) leg press test protocol started with 80–150 kg. Appropriate starting weights for each athlete were decided individually by asking about athlete's experience of weight training in seated leg press machine. At the starting point athlete's legs were extended and the weights were then lowered until the knees form the correct angle and then returned at the starting position as hard as possible. After each successful trial, the weights were increased by maximum 30 kg after the first trials and by minimum 10 kg after the last trials for the next attempt. Recovery period between the attempts was 2 min (Verdijk, van Loon, Meijer, & Savelberg, Hans H C M., 2009) and the test ends when 1RM was reached. Body mass normalized value was used in the analysis. Similar test has been proved to be reliable tool for measuring muscle strength (Levinger et al., 2009).

2.2.2. Maximal isokinetic quadriceps and hamstrings strength

Maximal concentric isokinetic quadriceps and hamstrings strength was measured at first study year (2011) in non-commercial dynamometer (name hidden). At the second study year (2012) the dynamometer was replaced by Biodex Multi-Joint System Pro dynamometer (Biodex System 4, Biodex Medical Systems, Inc., Shirley, NY, USA). The test procedure was the same either of the dynamometers used. The test range of motion was 90° through 15° of knee flexion with an angular velocity of 60°/s (Fig. 2). A standardized test protocol (Pasanen et al., 2015) with gradually increasing intensity were performed and the final test includes three repetitions with maximum strength. The maximal strength was reported as peak torque (N·m) recorded and body mass normalized value was used in the analysis. The strength difference between legs as well as hamstrings-to-quadriceps (HQ) strength ratio were calculated. Isokinetic strength testing has been established as reliable tool for assessing muscle strength (Brosky JA Jr, Nitz, Malone, Caborn, & Rayens, 1999).

To evaluate the reproducibility of measurements between the used two dynamometers, twelve 14–15 years old male soccer athletes (24 legs) were tested with both dynamometers by different testers who collected the data. Intraclass correlation coefficient (ICC) value (3,k) was 0.81 (95% CI, 0.43–0.93) for isokinetic quadriceps and 0.79 (95% CI, 0.47–0.91) for isokinetic hamstring strength measurement indicating good test-retest reliability of the tests.

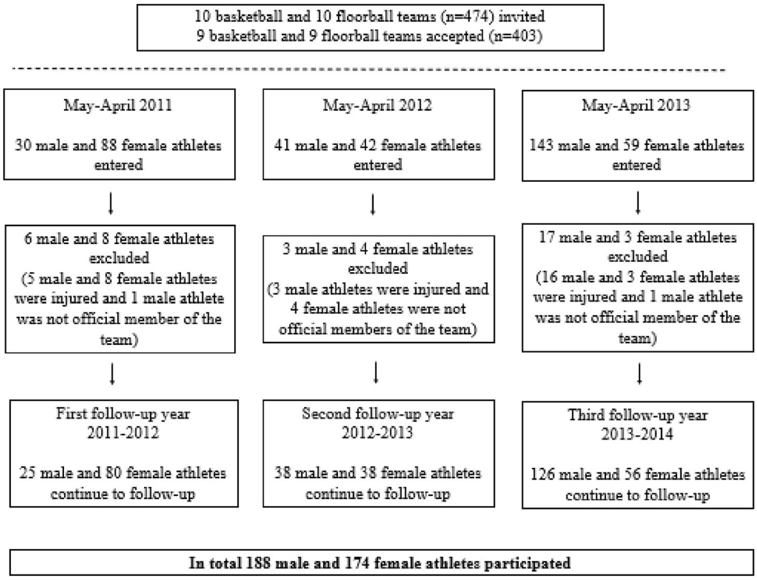

Fig. 1. The flow of athletes in the study.

Table 1
Demographic data and ankle injury history of participating athletes.

	Male			Female		
	All (n = 188)	Basketball (n = 93)	Floorball (n = 95)	All (n = 174)	Basketball (n = 96)	Floorball (n = 78)
Age (y)[a]	16.0 ± 1.6	15.2 ± 1.6	16.8 ± 1.2	15.4 ± 2.0	14.6 ± 1.6	16.5 ± 1.9
Height (cm)[b]	178.6 ± 8.1	179.0 ± 9.6	178.2 ± 6.3	167.4 ± 6.2	168.2 ± 6.4	166.5 ± 5.7
Weight (kg)[b]	69.2 ± 10.9	68.6 ± 13.0	69.8 ± 8.3	61.0 ± 8.6	61.0 ± 9.5	61.1 ± 7.3
BMI, (kg/m^2)[b]	21.6 ± 2.7	21.3 ± 3.0	22.0 ± 2.3	21.7 ± 2.7	21.5 ± 2.8	22.0 ± 2.5
Playing experience (y)[b]	8.1 ± 3.1	7.4 ± 3.2	8.8 ± 2.8	6.3 ± 2.5	6.4 ± 2.5	6.2 ± 2.5
Playing at adult level before entering the study[c]	9	3	6	23	0	23
Previous acute ankleinjury (n)[d]	108	61	47	99	53	46

[a] Age at the start of the follow-up. Values are presented as mean ± SD.
[b] Values are presented as mean ± SD.
[c] Values are presented as median (IQR).
[d] Values are presented as total number of injuries.

2.2.3. Maximal hip abductor strength

Maximal isometric hip abductor strength (kg) was tested with a hand-held dynamometer (Hydraulic Push-Pull Dynamometer, Baseline® Evaluation Instruments, White Plains, NY, USA). The test was perfomed with the athlete lying legs extended in a supine position on bench. The pelvis and the contralateral thigh were fixed with a belt and the athlete hold his or her arms across the chest during the test. The dynamometer was positioned approximately 2 cm proximal the lateral ankle malleolus with the leg in neutral position and the foot in slight dorsiflexion (Fig. 2). The dynamometer was applied in a fixed position and the athlete hold muscle contraction against the dynamometer for approximately two seconds (make-test). After one test trial the athlete performed two maximal contractions with a 10 s rest between the attempts (Johnson, Mille, Martinez, Crombie, & Rogers, 2004). The highest result was recorded and body mass normalized value was used in the analysis. The strength difference between legs was also calculated. Similar procedure has been showed to be reliable for assessing hip abductor strength (Thorborg, Petersen, Magnusson, & Holmich, 2010).

2.3. Injury and exposure registration

During a follow-up period (May 2011–;April 2014), all acute ankle injuries were registered by two study physicians. They contacted the teams once a week to check possible new injuries and after each injury reported, the injured athlete was interviewed by telephone using the structured questionnaire (Pasanen et al., 2015). Injury definition was modified from definition by Fuller and colleagues (Fuller et al., 2006). An injury was recorded if the athlete was unable to fully participate in matches or training during the next 24 h. Only injuries which occurred in a teams' scheduled training sessions or matches were included in this study. The injuries were classified as contact (ie. direct contact or strike to the involved ankle) or non-contact (ie. no direct contact to the involved ankle).

During the follow-up, the coach of each team recorded athletes' participation in trainings and matches. Athlete attendance in a training session (yes/no), duration of a training session (h) and attendance in each period of a match (yes/no) were recorded individually on a team diary. The diaries were returned after each

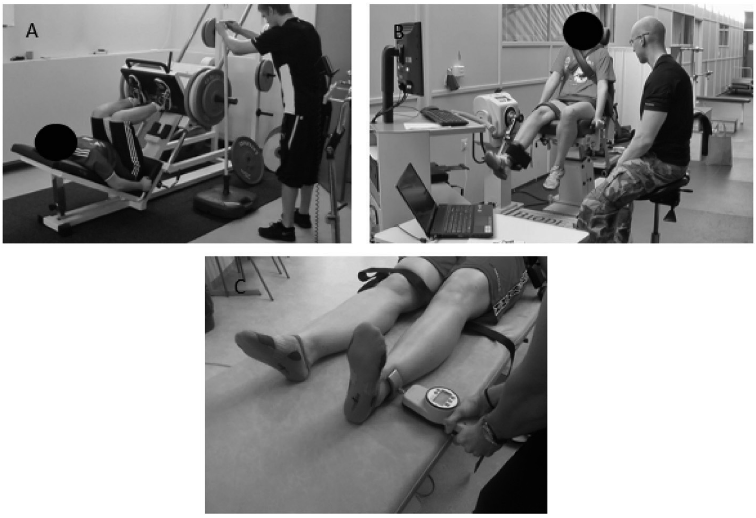

Fig. 2. A, The measurement of 1RM seated leg press strength. B, the measurement of maximal concentric isokinetic quadriceps and hamstrings strength; C, the measurement of maximal isometric hip abductor strength.

follow-up month and the individual monthly exposure time (h) were registered for all athletes. If an acute ankle injury occurred, the exposure hours of that month were estimated by dividing the days from the beginning of the month to the injury date by all days of the month and then by multiplying the result by the athlete's registered exposure hours of that month.

2.4. Statistical analysis

Descriptive data are presented as the mean ± standard deviation (SD) or the median and interquartile range (IQR) depending on the normality of distribution of variables. An independent-samples *t*-test was used to compare group differences for normally distributed variables and the Mann-Whitney *U* test for non-normally distributed variables. Depending on the distribution of the variables, Pearson's and Spearman's correlation coefficients were used to evaluate linear correlation between two variables. Injury incidences were calculated as the number of injuries per 1000 player-hours and reported with 95% CIs: ([*Incidence rate* − 1.96 * *Standard error of incidence rate*] * 1000 h) to ([*Incidence rate* + 1.96 * *Standard error of incidence rate*] * 1000 h). Recurrent injuries were included in incidence calculations.

Considering the study procedure, Cox regression models were chosen to analyse strength variables using the athlete or the leg as a unit of analysis. The unit of analysis was defined according to the strength variable representing either the characteristic of the athlete or of the leg (Brosky, Nitz, Malone, Caborn, & Rayens, 1999). The outcomes were a new acute (contact or non-contact) ankle injury and a new acute non-contact ankle injury. Exposure time (h) from the start of the follow-up until the first injury or the end of the follow-up were included in the models. Sports club was included in all models as random effect and the leg in the models using it as the unit of analysis. Unadjusted and adjusted models with predefined adjustement factors were made separately for male and female athletes. The adjustement factors that might mostly influence to the risk of ankle injury were selected in the following order: previous acute ankle injury, age, height, sport and playing at adult level. These adjustement factors were included in the models according to the number of injuries in each model, using estimation of 10 injuries needed per included variable (Peduzzi, Concato, Feinstein, & Holford, 1995). In the models using the athlete as the unit of analysis, previous injuries of ipsilateral or contralateral side were included, and in the models using the leg as a unit of analysis, only injuries of ipsilateral side were included.

Cox hazard ratios (HRs) per 1 SD increase with 95% CIs were calculated for each strength variable. *P* value < 0.05 were considered significant. A receiver operating characteristics (ROC) curve analysis was calculated to assess the combined sensitivity and specifity of a test in cases where significant associations between the strength variable and the outcome were found. The test was defined as "excellent" (0.90–1.00), "good" (0.80–0.89), "fair" (0.70–0.79), "poor" (0.60–0.69) and "fail" (0.50–0.59). Statistical analyses were conducted in SPSS for Windows (v.20.0.0; SPSS), except the regression models, which were conducted in R (v3.1.2; R Foundation for Statistical Computing).

3. Results

3.1. Injury and exposure characteristics

The mean follow-up period was 1.3 ± 0.6 and 1.7 ± 0.6 years in male and female athletes, respectively. The median total (matches and trainings) exposure was 289.9 (238.5) hours in males and 258.9 (365.1) in females.

In males, a total of 43 new acute ankle injuries occurred in 38 athletes and 24 of these were non-contact injuries. In addition, 12 players had one or more re-injuries to the same ankle. Fortyone (95%) of all acute ankle injuries in males were diagnosed as lateral ankle sprains. The overall and non-contact ankle injury incidence for males was 0.9 (95% CI, 0.7–1.1) and 0.5 (95% CI, 0.3–0.7) injuries per 1000 player-hours, respectively.

In females, there were 62 new acute ankle injuries in 55 athletes and 44 occurred in non-contact situations. Twelve athletes had also one or more re-injuries to the same ankle. Fifty-six (90%) of all acute ankle injuries were diagnosed as lateral ankle sprains. The overall and non-contact ankle injury incidence for females was 1.3

(95% CI, 1.0–1.6) and 0.9 (95% CI, 0.7–1.1) injuries per 1000 player-hours, respectively.

3.2. Unadjusted group differences

In males, 1RM leg press strength (kg/kg) was 10% greater in athletes who had any type of acute ankle injury (mean difference 0.3, P = 0.003) and 9% greater who had acute non-contact ankle injury (mean difference 0.25, P = 0.04). In addition, maximal isokinetic quadriceps strength (N·m/kg) was 7% greater in injured compared to uninjured legs in male athletes who suffered any type of acute ankle injury (mean difference 0.18, P = 0.01) (Appendix 1).

In females, 1RM leg press strength was 8% greater in athletes who suffered acute non-contact ankle injury (mean difference 0,19, P = 0.01) (Appendix 2).

3.3. Adjusted risk factor analyses

In males, greater 1RM leg press and maximal isokinetic quadriceps strength were associated with an increased risk of any type of acute ankle injury (HR for 1 SD increase, 1.63 [95% CI, 1.12–2.39]; P = 0.01 and 1.43 [95% CI, 1.01–2.01]; P = 0.04, respectively) (Table 2). .ROC curve analyses showed an area under the curve (AUC) of 0.64 for 1RM leg press and 0.62 for maximal isokinetic quadriceps strength test Correlation coefficients between age and 1RM leg press and between age and isokinetic quadriceps strength were 0.48 ($p < 0.001$) and 0.36 ($p < 0.001$), respectively.

In females, greater 1RM leg press strength and difference between legs in maximal hip abduction strength increased the risk of acute non-contact ankle injury (HR for 1 SD increase, 1.44 [95% CI, 1.03–2.02]; P = 0.03 and 1.44 [95% CI, 1.03–2.00]; P = 0.03, respectively) (Table 2). ROC curve analysis showed AUC:s of 0.63 for 1 RM leg press strength test and 0.57 for the strength difference between legs in hip abduction.

4. Discussion

The main findings of the study were that greater 1RM leg press and maximal quadriceps strength increased the risk of any type of acute ankle injury in youth male athletes and greater 1RM leg press strength and greater difference between legs in maximal hip abduction strength increased the risk of acute non-contact ankle injury in youth female athletes.

4.1. Muscle strength and acute ankle injury in males

Greater quadriceps strength has previously suggested to associate with the increased risk of hamstring strains (Freckleton & Pizzari, 2013), but to our knowledge, not with ankle injuries in male athletes. It is possible that older junior-aged male athletes are stronger and they practise and play more even in adult league teams thus being more time at risk to get an injury. However, we found no strong correlations between male athletes' age and 1RM leg press or maximal isokinetic quadriceps strength indicating that age alone is not sufficient enough to explain this finding. Nevertheless, stronger athletes might have been more mature and skilled otherwise. Strong athletes may also be able to run and change direction faster leading to greater mechanical forces and in this way the injury risk may increase. In addition, greater maximal knee or hip muscle strength does not necessarily mean that an athlete has a proper landing or direction change technique (Bandholm et al., 2011; Cronstrom, Creaby, Nae, & Ageberg, 2016). Poor technique combined with greater muscle mass and higher speed may increase ligament loading and ankle injury risk in stronger athletes compared to weaker lightweighted athletes (Fousekis, Tsepis, & Vagenas, 2012; Gribble et al., 2016; Nilstad, Andersen, Bahr, Holme, & Steffen, 2014).

Powers, Ghoddosi, Straub, and Khayambashi (2017) reported that lower maximal hip abduction strength increased the risk of

Table 2
Unadjusted and adjusted HR (per 1 SD increase) with 95% Cis for strength variables for ankle injuries in males and females.[a].

	Male				Female			
	Any type of ankle injury		Non-contact ankle injury		Any type of ankle injury		Non-contact ankle injury	
	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)	HR (95% CI)	Adjusted HR (95% CI)
Player as a unit of analysis								
Leg press (kg/kg)[b]	**1.63 (1.17–2.27)**	**1.63 (1.12–2.39)**[e]	1.39 (0.93–2.09)	1.34 (0.89–2.01)[d]	1.23 (0.93–1.63)	1.32 (0.96–1.80)[g]	**1.38 (1.01–1.88)**	**1.44 (1.03–2.02)**[f]
Quadriceps between- leg difference (N·m)[c]	1.23 (0.87–1.74)	1.18 (0.83–1.67)[e]	1.44 (0.95–2.20)	1.39 (0.90–2.14)[d]	0.84 (0.59–1.18)	0.85 (0.62–1.16)[g]	0.85 (0.59–1.22)	0.86 (0.62–1.21)[f]
Hamstring between- leg difference (N·m)[c]	1.10 (0.82–1.48)	1.08 (0.80–1.47)[e]	0,69 (0.41–1.16)	0.67 (0.39–1.16)[d]	1.00 (0.76–1.30)	1.00 (0.77–1.31)[g]	0.97 (0.70–1.34)	0.97 (0.70–1.34)[f]
Hip abduction between- leg difference (kg)[c]	1.10 (0.79–1.52)	1.02 (0.73–1.43)[e]	1.28 (0.88–1.87)	1.23 (0.85–1.79)[d]	1.15 (0.88–1.50)	1.14 (0.87–1.49)[g]	**1.44 (1.05–1.98)**	**1.44 (1.03–2.00)**[f]
Leg as a unit of analysis								
Quadriceps (N·m/kg)[b]	**1.50 (1.10–2.06)**	**1.43 (1.01–2.01)**[f]	1.06 (0.70–1.60)	0.99 (0.65–1.52)[d]	0.88 (0.68–1.15)	0.88 (0.66–1.17)[h]	0.84 (0.61–1.14)	0.85 (0.61–1.18)[f]
Hamstrings (N·m/kg)[b]	1.13 (0.83–1.53)	1.04 (0.74–1.45)[f]	0.80 (0.52–1.22)	0.74 (0.48–1.14)[d]	0.91 (0.69–1.19)	0.90 (0.67–1.21)[h]	0.84 (0.61–1.17)	0.82 (0.58–1.17)[f]
HQ ratio (%)	**0.71 (0.51–0.99)**	0.72 (0.52–1.00)[f]	0.71 (0.46–1.09)	0.72 (0.47–1.10)[d]	1.02 (0.77–1.35)	1.02 (0.77–1.37)[h]	0.98 (0.71–1.36)	0.95 (0.67–1.33)[f]
Hip abduction (kg/kg)[b]	0.88 (0.63–1.24)	0.88 (0.62–1.24)[f]	1.02 (0.68–1.55)	1.04 (0.69–1.57)[d]	1.09 (0.84–1.42)	1.10 (0.84–1.43)[h]	1.21 (0.88–1.65)	1.21 (0.88–1.65)[f]

[a] Values in parentheses are 95% CIs. Significant results are marked in bold. HR, Hazard ratio. HQ ratio, hamstrings to quadriceps strength ratio.
[b] Body mass normalized values.
[c] Strenght difference between stronger and weaker leg.
[d] Adjustement factor: previous acute ankle injury.
[e] Adjustement factors: previous acute ankle injury and age.
[f] Adjustement factors: previous acute ankle injury, age and height.
[g] Adjustement factors: previous acute ankle injury, age, height and sport.
[h] Adjustement factors: previous acute ankle injury, age, height, sport and playing at adult level.

non-contact lateral ankle sprain in a group of junior and adult male soccer athletes (aged 13–34 years). In the present study, such association was not found. Also in Powers et al. (2017) study, the maximal hip abductor strength measurement was the make-test and it was performed using the hand-held dynamometer. However, in contrast to our study, athletes' individual exposure time was not measured. It is possible that some athletes with lower hip abductor strength could have been at increased risk of injury due to more playing and training time (Bahr & Holme, 2003a). Supporting findings of our study, McHugh et al. (2006) reported that maximal hip abductor strength was not a predictor for non-contact lateral ankle sprain in a group of male and female high school athletes. De Ridder, Witvrouw, Dolphens, Roosen, and Van Ginckel (2017) found also no association between maximal hip abduction strength and lateral ankle sprain in youth male soccer athletes but reported that lower maximal hip extensor strength increased the risk of these injuries. Although we did not measure maximal hip extension strength, we would expect that greater, rather than lower, hip extension strength might have increased the risk of ankle sprain because greater 1RM leg press strength increased the risk of these injuries in the present study.

4.2. Muscle strength and acute ankle injury in females

The findings concerning female players extend previous findings from a prospective Norwegian study in female elite soccer athletes. Nilstad et al. (2014) found no association between maximal isokinetic quadriceps and hamstrings strength, HQ ratio or maximal hip abduction strength and any ankle injury. Although the athletes in Nilstad et al. (2014) study were considerably older (20.9 years on average) the selected muscle strength variables did not associate with ankle injury risk in females. In contrast to Nilstad et al. (2014) study, we found that greater 1RM leg press strength increase the risk of acute non-contact ankle injury. Lower 1RM leg press strength has been found also to increase the risk of acute knee injury in young female athletes (Ryman Augustsson & Ageberg, 2017).

We found that greater difference between legs in maximal hip abduction strength increased the risk of acute non-contact ankle injury in youth female athletes. The mechanistic connection between this strength imbalance and non-contact ankle injury is unclear and it is possible that these female athletes also had strength imbalances in other LE or core muscles. The strength imbalance in hip abductors can also be a compensatory mechanism to inadequate or false kinetic patterns in athletic movements like landings, turnings and running, in which non-contact ankle injuries commonly occur (Woods, Hawkins, Hulse, & Hodson, 2003b). Thus, this finding should be interpreted with caution.

4.3. Clinical implications

Although we found that stronger male and female athletes were at increased risk to get an acute ankle injury, it does not mean that LE strength exercises should be taken out of injury prevention programmes in youth athletes. Correspondingly, we believe that youth female athletes should not exclusively concentrate on to strengthen hip abductor muscles of the weaker leg. It should be noticed that we measured maximal muscle strength, but in neuromuscular injury prevention programs, muscle strength training usually contains exercises with low or no additional weights while concentrating on proper technique with gradually increasing volume and intensity (Lauersen, Andersen, & Andersen, 2018). As a result of increased limb length and body mass in growth spurt during adolescence, moments of inertia in limbs increase affecting limb dynamics and muscle strength required to perform movements (Hawkins & Metheny, 2001). At the same time, sensorimotor functions continue to develop and there may be even periods of regressions in some of these, which may contribute to the injury risk (Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2012). Therefore, neuromuscular training including low- or body weight strength exercises can be recommended to youth athletes for the prevention of acute and also overuse LE injuries (Coppack, Etherington, & Wills, 2011; Walden, Atroshi, Magnusson, Wagner, & Hagglund, 2012; Zouita et al., 2016).

Regardless of significant associations between the muscle strength and ankle injury in our study, substantial overlap between the test results in injured and uninjured athletes existed leading “fail” to “poor” combined sensitivity and specifity for the strength tests meaning that the tests can correctly classify <70% of injured and uninjured athletes. Therefore, in clinical practice, the muscle strength tests as measured in the present study cannot be recommended alone as injury screening tools for acute ankle injury in youth athletes.

4.4. Study strengths and limitations

This study had several strengths. First, all the data was collected prospectively. Second, the accuracy of ankle injury data collection was good, because study physicians contacted coaches once a week. Third, individually collected exposure data enabled the use of Cox regression in statistical analyses (Brosky, Nitz, Malone, Caborn, & Rayens, 1999). Finally, the strength risk factors were measured with standard and simple procedures easy to use in clinical practice.

One main limitation of the study was that we measured only muscle strength, but ankle injury is likely a result of the complex interaction between many internal (athlete-related) and external (environmental) risk factors (Bahr & Krosshaug, 2005; Meeuwisse, 1994). However, we took into analyses several other potential risk factors as adjustement factors. Another main limitation was, that strength measurements were not repeated and thus the strength values might have been changed during the 3-year follow-up. In addition, we did not take the influence of lever arm (limb length) into account for 1RM leg press and hip abduction strength measurements (Bakken et al., 2018; McHugh et al., 2006). Finally, because the study cohort comprised of youth floorball and basketball athletes, the findings may not be applicable to adult athletes or athletes from other youth sports.

5. Conclusion

Our 3-year prospective study showed that greater 1RM leg press and maximal quadriceps strength increased the risk of any type of acute ankle injury in youth male athletes while greater 1RM leg press strength and greater difference between legs in maximal hip abduction strength increased the risk of acute non-contact ankle injury in youth female athletes. However, according to the ROC curve analysis, these strength variables as measured in the present study cannot be used alone as screening tools for acute ankle injury in youth team-sport athletes.

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Declaration of competing interest

The authors declare that the results of the study are presented clearly, honestly, and without fabrication, calcification, or inappropriate data manipulation, and statement that results of the present study do not constitute endorsement by ACSM. The authors declare that there is no conflict of interest regarding the publication of this paper.

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