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

Year: 2021

Version: Accepted version (Final draft)

Hietamo, J., Pasanen, K., Leppänen, M., Steffen, K., Kannus, P., Heinonen, A., Mattila, V., & Parkkari, J. (2021). Association between lower extremity muscle strength and acute ankle injury in youth team-sports athletes. Physical Therapy in Sport, 48, 188-195

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.

Keywords: SPORT INJURY; INJURY RISK; YOUTH SPORT

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 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 standardised 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 minutes (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.

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 second 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 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 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 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 hours) to ([*Incidence rate* + 1.96 * *Standard error of incidence rate*] * 1000 hours). 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 (Bahr & Holme, 2003b). 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 operaiting 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.

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 et al. (2017) reported that lower maximal hip abduction strength increased the risk of 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 et al. (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.

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.

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 excercises should be taken out of injury prevention programmes in youth athetes. 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 weigth 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.

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 (Bahr & Holme, 2003). 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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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 ankle injury (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.

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.

Fig. 1. The flow of athletes in the study

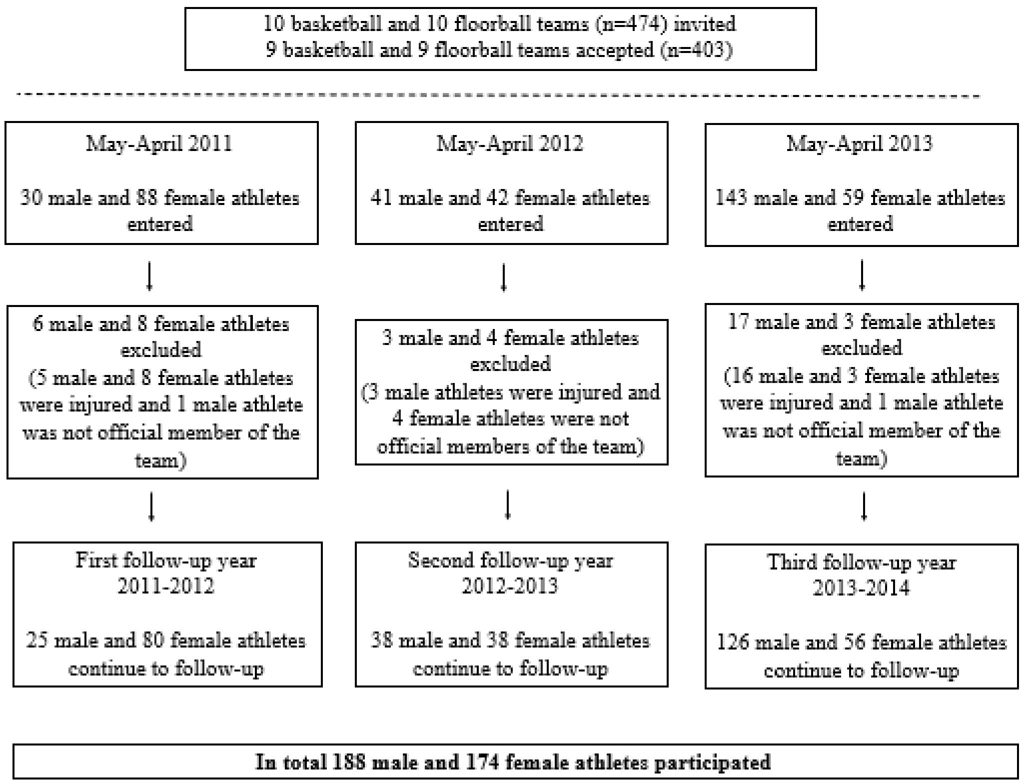

Fig. 2. A, The measurement of 1RM seated leg press strength. B, the measurement of maximal concentric isokinetic quadriceps and hamstrings strength; C, the measurement of maximal isometric hip abductor strength