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3 sports athletes. *Physical Therapy in Sport*, 48, 188-195
4

5 ABSTRACT

6 **Objectives:** To investigate lower extremity muscle strength as risk factor for an acute ankle injury
7 in youth athletes.

8 **Design:** Cohort study.

9 **Setting:** Basketball and floorball clubs.

10 **Participants:** 188 youth (≤ 21) male and 174 female athletes.

11 **Main outcome measures:** 1RM leg press, maximal concentric isokinetic quadriceps and
12 hamstrings as well as maximal isometric hip abductor strength were measured and athletes were
13 followed for an acute ankle injury up to three years. Cox regression models were used in statistical
14 analyses.

15 **Results:** In males, greater 1RM leg press and maximal quadriceps strength increased the risk of any
16 type of acute ankle injury (Hazard ratio [HR] for 1 SD increase, 1.63 [95% CI, 1.12–2.39] and 1.43
17 [95% CI, 1.01–2.01], respectively). In females, greater 1RM leg press and difference between legs
18 in hip abduction strength increased the risk of acute non-contact ankle injury (HR for 1 SD increase,
19 1.44 [95% CI, 1.03–2.02] and 1.44 [95% CI, 1.03–2.00], respectively). However, ROC curve
20 analyses showed AUC:s of 0.57-0.64 indicating “fail” to “poor” combined sensitivity and specificity
21 of these tests.

22 **Conclusion:** Greater strength in both sexes along with asymmetry in hip abductor strength in
23 females increased the risk of acute ankle injury.

24

25 **Keywords:** SPORT INJURY; INJURY RISK; YOUTH SPORT

26 **1. INTRODUCTION**

27 Incidence of ankle injury is high in youth team sports (Borowski, Yard, Fields, & Comstock, 2008;
28 Emery, Carolyn A., Meeuwisse, & Hartmann, 2005; Olsen, O-E, Myklebust, Engebretsen, & Bahr,
29 2006; Powell & Barber-Foss, 2000). Lateral ankle sprain is observed most frequently (Sankey,
30 Brooks, Kemp, & Haddad, 2008; Starkey, 2000; Woods, Hawkins, Hulse, & Hodson, 2003a).
31 Ankle sprain can lead to a marked loss of practicing and playing time (Cloke, Spencer, Hodson, &
32 Deehan, 2009) and often evolve persistent pain, weakness and chronic instability possibly resulting
33 in lower sport activity levels or even change of sports (Anandacoomarasamy & Barnsley, 2005).

34 Identifying risk factors that are modifiable and clinically easy to test are essential
35 before planning injury prevention programs (Bahr & Krosshaug, 2005). The role of lower extremity
36 (LE) muscle strength as a risk factor for sport injury is controversial. Lower quadriceps and
37 hamstrings strength or strength imbalances between these muscles have shown to increase the risk
38 of anterior cruciate ligament injury and hamstring strain (Croisier, Ganteaume, Binet, Genty, &
39 Ferret, 2008; Myer et al., 2009; Soderman, Alfredson, Pietila, & Werner, 2001) although contrary
40 results also exist (Bennell et al., 1998; Uhorchak et al., 2003). In our previously published study,
41 lower hip abduction strength increased the risk of acute knee injury in youth male athletes (Hietamo
42 et al., 2020).

43 There are several studies investigating ankle dorsiflexion, plantar flexion, inversion,
44 eversion, dorsiflexion and plantar flexion strength as well as strength ratios between these as risk
45 factors for ankle injury (Beynon, Renstrom, Alosa, Baumhauer, & Vacek, 2001; Wang, Chen,
46 Shiang, Jan, & Lin, 2006; Willems, T. M. et al., 2005; Willems, Tine Marieke et al., 2005).
47 However, based on kinetic chain theories, impairments of proximal core and hip muscle function

48 are suggested to increase the likelihood of uncontrolled joint displacements distally and occurrence
49 of distal LE injury (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Willson, Dougherty,
50 Ireland, & Davis, 2005). Lower hip abduction strength has found to associate with chronic ankle
51 sprains (Friel, McLean, Myers, & Caceres, 2006), but in another study, no association between hip
52 muscle strength and the risk of non-contact lateral ankle sprain was reported in high school athletes
53 (McHugh, Tyler, Tetro, Mullaney, & Nicholas, 2006). In addition, alterations in knee kinematics in
54 jump landing task have found in subjects with chronic ankle instability (Gribble & Robinson, 2009)
55 and neuromuscular training including quadriceps and hamstrings strengthening exercises have
56 shown to decrease the risk of acute ankle injury in youth athletes (Emery, C. A. & Meeuwisse,
57 2010; Olsen, Odd-Egil, Myklebust, Engebretsen, Holme, & Bahr, 2005). Therefore, lower
58 quadriceps and hamstrings strength may also be considered as risk factors for acute ankle injury.

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

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71 2. METHODS

72 2.1. Study design and participants

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

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

91 2.2. Muscle strength tests

92 The muscle strength tests were part of a baseline test battery used to investigate potential
93 anatomical, biomechanical and neuromuscular risk factors for injuries. The complete test protocol
94 with standardised warm-up procedures before each test is described elsewhere (Pasanen et al.,
95 2015).

96 2.2.1. Maximal one-repetition leg press strength

97 A seated leg press machine (Technogym®, Gambettola, Italy) was used to measure a combined
98 maximal extension strength of LE muscles. The distance between feet was 20 cm and end of shoes
99 were 10 cm above from the lowest end of the foot plate. The back of the seat was set on 30° angle
100 relative to the floor. A vertical bar was placed at the point where the knees reached the target knee
101 angle of 80° (**Fig. 2**). The target knee angle was measured with a goniometer (HiRes, Baseline®
102 Evaluation Instruments, White Plains, NY, USA). A standardized warm-up protocol consisted three
103 sets with gradually increasing weights (Pasanen et al., 2015). The one-repetition maximum (1RM)
104 leg press test protocol started with 80–150 kg. Appropriate starting weights for each athlete were
105 decided individually by asking about athlete's experience of weight training in seated leg press
106 machine. At the starting point athlete's legs were extended and the weights were then lowered until
107 the knees form the correct angle and then returned at the starting position as hard as possible. After
108 each successful trial, the weights were increased by maximum 30 kg after the first trials and by
109 minimum 10 kg after the last trials for the next attempt. Recovery period between the attempts was
110 2 minutes (Verdijk, van Loon, Meijer, & Savelberg, Hans H C M., 2009) and the test ends when
111 1RM was reached. Body mass normalized value was used in the analysis. Similar test has been
112 proved to be reliable tool for measuring muscle strength (Levinger et al., 2009).

113 2.2.2. Maximal isokinetic quadriceps and hamstrings strength

114 Maximal concentric isokinetic quadriceps and hamstrings strength was measured at first study year
115 (2011) in non-commercial dynamometer (name hidden). At the second study year (2012) the

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

126 To evaluate the reproducibility of measurements between the used two dynamometers,
127 twelve 14–15 years old male soccer athletes (24 legs) were tested with both dynamometers by
128 different testers who collected the data. Intraclass correlation coefficient (ICC) value (3,k) was 0.81
129 (95% CI, 0.43–0.93) for isokinetic quadriceps and 0.79 (95% CI, 0.47–0.91) for isokinetic
130 hamstring strength measurement indicating good test-retest reliability of the tests.

131 2.2.3. Maximal hip abductor strength

132 Maximal isometric hip abductor strength (kg) was tested with a hand-held dynamometer (Hydraulic
133 Push-Pull Dynamometer, Baseline® Evaluation Instruments, White Plains, NY, USA). The test was
134 performed with the athlete lying legs extended in a supine position on bench. The pelvis and the
135 contralateral thigh were fixed with a belt and the athlete hold his or her arms across the chest during
136 the test. The dynamometer was positioned approximately 2 cm proximal the lateral ankle malleolus
137 with the leg in neutral position and the foot in slight dorsiflexion (**Fig. 2**). The dynamometer was
138 applied in a fixed position and the athlete hold muscle contraction against the dynamometer for
139 approximately two seconds (make-test). After one test trial the athlete performed two maximal

140 contractions with a 10 second rest between the attempts (Johnson, Mille, Martinez, Crombie, &
141 Rogers, 2004). The highest result was recorded and body mass normalized value was used in the
142 analysis. The strength difference between legs was also calculated. Similar procedure has been
143 showed to be reliable for assessing hip abductor strength (Thorborg, Petersen, Magnusson, &
144 Holmich, 2010).

145 2.3. Injury and exposure registration

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

155 During the follow-up, the coach of each team recorded athletes' participation in
156 trainings and matches. Athlete attendance in a training session (yes/no), duration of a training
157 session (h) and attendance in each period of a match (yes/no) were recorded individually on a team
158 diary. The diaries were returned after each follow-up month and the individual monthly exposure
159 time (h) were registered for all athletes. If an acute ankle injury occurred, the exposure hours of that
160 month were estimated by dividing the days from the beginning of the month to the injury date by all
161 days of the month and then by multiplying the result by the athlete's registered exposure hours of
162 that month.

163 2.4. Statistical analysis

164 Descriptive data are presented as the mean \pm standard deviation (SD) or the median and
165 interquartile range (IQR) depending on the normality of distribution of variables. An independent-
166 samples *t* test was used to compare group differences for normally distributed variables and the
167 Mann-Whitney *U* test for non-normally distributed variables. Depending on the distribution of the
168 variables, Pearson's and Spearman's correlation coefficients were used to evaluate linear correlation
169 between two variables. Injury incidences were calculated as the number of injuries per 1000 player-
170 hours and reported with 95% CIs: ($[Incidence\ rate - 1.96 * Standard\ error\ of\ incidence\ rate] * 1000$
171 $hours$) to ($[Incidence\ rate + 1.96 * Standard\ error\ of\ incidence\ rate] * 1000$ hours). Recurrent
172 injuries were included in incidence calculations.

173 Considering the study procedure, Cox regression models were chosen to analyse
174 strength variables using the athlete or the leg as a unit of analysis. The unit of analysis was defined
175 according to the strength variable representing either the characteristic of the athlete or of the leg
176 (Bahr & Holme, 2003b). The outcomes were a new acute (contact or non-contact) ankle injury and
177 a new acute non-contact ankle injury. Exposure time (h) from the start of the follow-up until the
178 first injury or the end of the follow-up were included in the models. Sports club was included in all
179 models as random effect and the leg in the models using it as the unit of analysis. Unadjusted and
180 adjusted models with predefined adjustment factors were made separately for male and female
181 athletes. The adjustment factors that might mostly influence to the risk of ankle injury were
182 selected in the following order: previous acute ankle injury, age, height, sport and playing at adult
183 level. These adjustment factors were included in the models according to the number of injuries in
184 each model, using estimation of 10 injuries needed per included variable (Peduzzi, Concato,
185 Feinstein, & Holford, 1995). In the models using the athlete as the unit of analysis, previous injuries
186 of ipsilateral or contralateral side were included, and in the models using the leg as a unit of
187 analysis, only injuries of ipsilateral side were included.

188 Cox hazard ratios (HRs) per 1 SD increase with 95% CIs were calculated for each
189 strength variable. *P* value < 0.05 were considered significant. A receiver operating characteristics
190 (ROC) curve analysis was calculated to assess the combined sensitivity and specificity of a test in
191 cases where significant associations between the strength variable and the outcome were found. The
192 test was defined as “excellent” (0.90–1.00), “good” (0.80–0.89), “fair” (0.70–0.79), “poor” (0.60–
193 0.69) and “fail” (0.50–0.59). Statistical analyses were conducted in SPSS for Windows (v.20.0.0;
194 SPSS), except the regression models, which were conducted in R (v3.1.2; R Foundation for
195 Statistical Computing).

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211 3. RESULTS

212 3.1. Injury and exposure characteristics

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

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

221 In females, there were 62 new acute ankle injuries in 55 athletes and 44 occurred in
222 non-contact situations. Twelve athletes had also one or more re-injuries to the same ankle. Fifty-six
223 (90%) of all acute ankle injuries were diagnosed as lateral ankle sprains. The overall and non-
224 contact ankle injury incidence for females was 1.3 (95% CI, 1.0–1.6) and 0.9 (95% CI, 0.7–1.1)
225 injuries per 1000 player-hours, respectively.

226 3.2. Unadjusted group differences

227 In males, 1RM leg press strength (kg/kg) was 10 % greater in athletes who had any type of acute
228 ankle injury (mean difference 0.3, $P = 0.003$) and 9 % greater who had acute non-contact ankle
229 injury (mean difference 0.25, $P = 0.04$). In addition, maximal isokinetic quadriceps strength

230 (N·m/kg) was 7% greater in injured compared to uninjured legs in male athletes who suffered any
231 type of acute ankle injury (mean difference 0.18, $P = 0.01$) (**Appendix 1**).

232 In females, 1RM leg press strength was 8% greater in athletes who suffered acute non-
233 contact ankle injury (mean difference 0.19, $P = 0.01$) (**Appendix 2**).

234 3.3. Adjusted risk factor analyses

235 In males, greater 1RM leg press and maximal isokinetic quadriceps strength were associated with
236 an increased risk of any type of acute ankle injury (HR for 1 SD increase, 1.63 [95% CI, 1.12–
237 2.39]; $P = 0.01$ and 1.43 [95% CI, 1.01–2.01]; $P = 0.04$, respectively) (**Table 2**). ROC curve
238 analyses showed an area under the curve (AUC) of 0.64 for 1RM leg press and 0.62 for maximal
239 isokinetic quadriceps strength test. Correlation coefficients between age and 1RM leg press and
240 between age and isokinetic quadriceps strength were 0.48 ($p < 0.001$) and 0.36 ($p < 0.001$),
241 respectively.

242 In females, greater 1RM leg press strength and difference between legs in maximal
243 hip abduction strength increased the risk of acute non-contact ankle injury (HR for 1 SD increase,
244 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**
245 **2**). ROC curve analysis showed AUC:s of 0.63 for 1 RM leg press strength test and 0.57 for the
246 strength difference between legs in hip abduction.

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255 **4. DISCUSSION**

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

260 Muscle strength and acute ankle injury in males

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

275 Powers et al. (2017) reported that lower maximal hip abduction strength increased the
276 risk of non-contact lateral ankle sprain in a group of junior and adult male soccer athletes (aged 13-
277 34 years). In the present study, such association was not found. Also in Powers et al (2017) study,
278 the maximal hip abductor strength measurement was the make-test and it was performed using the
279 hand-held dynamometer. However, in contrast to our study, athletes' individual exposure time was
280 not measured. It is possible that some athletes with lower hip abductor strength could have been at
281 increased risk of injury due to more playing and training time (Bahr & Holme, 2003a). Supporting
282 findings of our study, McHugh et al. (2006) reported that maximal hip abductor strength was not a
283 predictor for non-contact lateral ankle sprain in a group of male and female high school athletes. De
284 Ridder et al. (2017) found also no association between maximal hip abduction strength and lateral
285 ankle sprain in youth male soccer athletes but reported that lower maximal hip extensor strength
286 increased the risk of these injuries. Although we did not measure maximal hip extension strength,
287 we would expect that greater, rather than lower, hip extension strength might have increased the
288 risk of ankle sprain because greater 1RM leg press strength increased the risk of these injuries in the
289 present study.

290 Muscle strength and acute ankle injury in females

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

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

308 Clinical implications

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

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

331 Study strengths and limitations

332 This study had several strengths. First, all the data was collected prospectively. Second, the
333 accuracy of ankle injury data collection was good, because study physicians contacted coaches once
334 a week. Third, individually collected exposure data enabled the use of Cox regression in statistical
335 analyses (Bahr & Holme, 2003). Finally, the strength risk factors were measured with standard and
336 simple procedures easy to use in clinical practice.

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

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350 **5. CONCLUSION**

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

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546 **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

547 ^aAge at the start of the follow-up. Values are presented as mean ± SD.548 ^bValues are presented as mean ± SD.549 ^cValues are presented as median (IQR).550 ^dValues are presented as total number of injuries.

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569 **Table 2. Unadjusted and adjusted HR (per 1 SD increase) with 95% Cis for strength variables**
 570 **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) [§]	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) [§]	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) [§]	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) [§]	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

571 ^aValues in parentheses are 95% CIs. Significant results are marked in bold. HR, Hazard ratio. HQ ratio, hamstrings to quadriceps
 572 strength ratio.

573 ^bBody mass normalized values.

574 ^cStrenght difference between stronger and weaker leg.

575 ^dAdjustement factor: previous acute ankle injury.

576 ^eAdjustement factors: previous acute ankle injury and age.

577 ^fAdjustement factors: previous acute ankle injury, age and height.

578 [§]Adjustement factors: previous acute ankle injury, age, height and sport.

579 ^hAdjustement factors: previous acute ankle injury, age, height, sport and playing at adult level.

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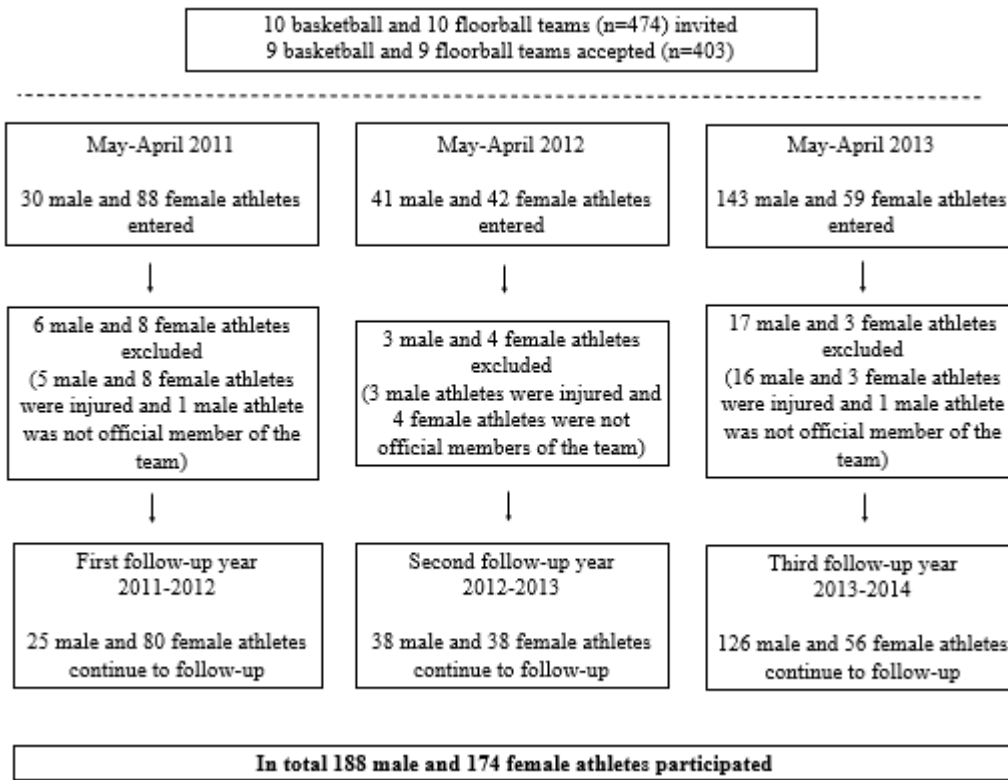
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586 **Fig. 1.** The flow of athletes in the study

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



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