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Investigation of knee control as a lower extremity injury risk factor: A prospective study in youth football

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ABSTRACT

This prospective study in youth football examined the relationship between frontal plane knee projection angle (FPKPA) during the single-leg squat and sustaining an acute lower extremity injury or acute non-contact lower extremity injury. Secondly, side-to-side asymmetry in FPKPA and sex as injury risk factors were explored. In addition, we investigated the influence of age, sex and leg dominance on the FPKPA. A total of 558 youth football players (U11 to U14), participated in the single-leg squat and prospective injury registration. FPKPA was not found as a risk factor for injuries at this age. There was no difference in the mean FPKPA between sexes. However, FPKPA was associated with age; oldest subjects displayed the smallest FPKPA. Among boys, the frontal plane knee control improved by age. Among girls, the relationship between age and FPKPA was not as clear but the oldest girls displayed the smallest mean FPKPA in the study (12.2°$\pm$ 8.3°). The FPKPA was greater on the dominant kicking leg compared to the non-dominant support leg (P<0.001 for boys, P=0.001 for girls). However, side-to-side asymmetry in FPKPA was not associated with future injuries. In conclusion, frontal plane knee control in the single-leg squat was not associated with lower extremity injuries among young football players.

KEYWORDS

athletic injuries, leg injuries, risk factors, risk assessment, soccer, youth sports

INTRODUCTION

With football (soccer) being the most popular sport in the world, football injuries have been an interest of sports medicine research for several decades.[1,2] Among the young football players under the age of 14 years, the knowledge of potentially modifiable lower extremity injury risk factors is still limited.

Sports participation is a major cause of injuries among youth.[3] In addition to short term consequences of sports injuries, it is important to address the long-term outcomes. Sports injuries, especially knee injuries, can lead to higher likelihood of overweight or obesity and reduced knee function[4], and higher risk of osteoarthritis later in life.[5] Acute lower extremity injuries are the most common injuries in youth football, with ankle, knee and thigh being the most frequently injured body parts.[2] Among children, football is a safe sport and injuries are rarely serious.[6] However, in academy youth football (ages 9 to 19 years), each injury, on average, stopped the player from participating in normal activities for 21.9 days.[7] The youth players miss about 6% of their development time through injuries.[7] There is a clear need to prevent injuries during the valuable developmental years. Neuromuscular control is modifiable through training[8] and neuromuscular training has been shown to improve knee control[9,10] and reduce injuries.[11–13]

The single-leg squat (SLS) is commonly used in clinical practice to identify reduced frontal plane knee control, which can manifest as knee valgus. Knee valgus can be harmful, since it alters the loads experienced be different tissues in the lower extremities. If the ability to control trunk, hip and knee motions during athletic tasks is poor, the athlete can allow the ground reaction forces to control the lower extremity alignment.[14] This may lead to high loads on the knee ligaments and could be a mechanism contributing to lower extremity injuries.[15] In addition to strength and neuromuscular activation of hip and trunk muscles, ankle function can also contribute to frontal plan knee motions. If ankle dorsiflexion is limited, for example due to decreased extensibility of the gastrocnemius/soleus complex, athlete might try to compensate for this by moving their knee medially towards valgus during athletic tasks.[16,17]

The two-dimensional (2D) video analysis method of the SLS is a valid[18] and reliable[19,20] tool for measuring frontal plane knee control. Previous studies have associated greater frontal plane knee projection angle (FPKPA) during the SLS with reduced hip abduction strength.[21–23] For every 1% improvement in hip abduction strength normalized to body weight, the FPKPA would improve by 0.2°.[22] The reduced hip abduction strength interacting with increased range of passive hip internal rotation contributes to a greater FPKPA.[24] Individuals with poor frontal plane control use a hip adductor dominant strategy during the SLS.[25] Other strength measurements associated with frontal plane knee control are knee flexion and knee extension[21], trunk side flexion[26] and hip external rotation.[27] A recent study on children and adolescents found no differences between boys and girls in the SLS performance scores based on visual assessement.[28] In our previous study, greater FPKPA during the SLS was associated with a higher risk of acute non-contact lower extremity injury and acute non-contact ankle injury in young (mean age 15.7 years) team sport athletes[29] but there are no previous studies on this topic in subjects under the age of 14 years.

The specific objective of this study was to investigate the association between FPKPA during the SLS and acute contact and non-contact lower extremity injuries in youth football players. The secondary aim was to investigate if sex or side-to-side asymmetry of FPKPA is associated with acute lower extremity or acute non-contact lower extremity injury. In addition, we set out to study the effects of age, sex and leg dominance on FPKPA.

METHODS

Study design and participants

This study is part of a cluster-randomized controlled trial on sports injury prevention in youth football (RCT ISRCTN14046021). The cohort in the present study consists of the control group of this RCT (n=737). Players who did not participate in the baseline SLS (n=163) or the injury registration (n=6) were excluded. In addition, the players who dropped out during the follow-up (n=10) were excluded from the current study since equal length of follow-up was necessary for the analysis. Numbers of subjects in each stage of the study are presented in Figure 1. The study was carried out in collaboration with Sami Hyypiä Academy, the training and research centre of Finnish football. Every second year, the Sami Hyypiä Academy selects about 20 youth clubs to participate in the player development monitoring system in which the talented U11 to U14 boys and girls participate on a three-day player development monitoring event twice a year. Every player who was an official member of the participating team and had no major injury at baseline was eligible to enter the study. All players and their parent/legal guardian provided written informed consent. The study was approved by the Ethics Committee of Pirkanmaa Hospital District (ETL-code R13110).

Baseline measurements

During their team's player development monitoring event in the fall 2014 (end of September to the beginning of December), the subjects participated in the SLS and height and weight measurements. From height and weight, body mass index (BMI, kg/m^2) was calculated. Each subject completed a baseline questionnaire, which included questions about the subject's age, sex, years of playing football, dominant leg, family history of musculoskeletal disorders, chronic illnesses, orthopaedic surgeries, menstrual cycle and previous injuries. The players were categorised into age groups of under 11 years (U11), under 12 years (U12), under 13 years (U13) and under 14 years (U14) by their age at the baseline test. The 18 players, who had not yet turned 10 years, were included in U11.

The test protocol for the SLS and the 2D video analysis method is based on the work of Stensrud et al.[20] and has been described in detail previously.[30] An alteration to the previous protocol was made by cutting out the warm-up. The warm-up was not considered necessary since in the present study the SLS test was not followed by the vertical drop jump test, as had been the case in previous studies.[20,31] First, square pieces of sports tape were attached to the left and right anterior superior iliac spine and tuberositas tibiae. Secondly, to standardize the knee flexion, the player performed a two-leg squat to 90° knee flexion, measured with a plastic goniometer (Baseline, USA). At 90° knee flexion, a string with a metal object at the distal end was attached to the lateral side of the thigh. The string was adjusted to the length in which the metal object would slightly touch the ground. This was repeated on the other leg. When the player performed the SLS on a metal plate, they could hear the metal object touching the plate when they reached the 90° knee flexion. Each player was allowed one practise attempt before they performed three SLSs to 90° knee flexion on right leg and repeated the procedure on left leg. The players were instructed to hold their hands at their waist and keep their eyes focused straight ahead during the trial. To capture the 2D frontal plane knee joint kinematics, the trials were recorded by a high definition video camera (Panasonic HDC-SD9C, Panasonic, Japan) positioned 4.5 m in front of the metal plate.

The 2D video analysis was performed by the primary investigator (A.M.R) using a Java-based computer software (ImageJ, National Institutes of Health). In the 2D video analysis, the FPKPA was measured from each valid squat. The squat was deemed invalid if the non-weight-bearing leg was held in the front or to the side or it touched the floor or if the player fell, looked down or moved their hands from the waist. The mean FPKPA for the right and the left leg were calculated and a minimum of two valid squats per leg were required. The FPKPA was calculated as the intersection of a line created by the anterior superior iliac spine and knee joint centre and the line created by the knee join centre and the ankle joint centre. Neutral alignment was considered 0°, positive values represented valgus alignment, and negative values represented varus alignment. The measurement of FPKPA is presented in Figure 2. In addition to mean FPKPA, side-to-side difference in the mean FPKPA between the two lower extremities was calculated (FPKPA asymmetry).

Injury definition and injury registration

Injury registration was carried out by text messaging. The follow-up period lasted for 20 weeks, from January to June. After each follow-up week, the player's parent/legal guardian received a text message regarding new injuries: "Has your child had any musculoskeletal complaint or injuries during the previous seven days (yes/no)." After each complaint or injury, the study physiotherapists contacted the injured player and/or their parent/legal guardian and collected details of the injury by standardized phone interview.

An injury was defined according to Fuller et al.[32] *'any physical complaint sustained by a player that result from football training or playing, causing a need for medical attention or time loss from fully football activities.'* The player was defined as injured until he/she was able to train and play normally again. The present study focused on the acute lower extremity (hip/groin/thigh/knee/shin/calf/ankle/foot) injuries. Non-contact injuries were defined as injuries that resulted without direct contact to the injured body part.

Statistical methods

To consider the possibly non-linear relationship between intrinsic factors and the risk of injury[33], categorical variables were formed based on the continuous variables utilizing the cohort mean and standard deviation (SD). Age, height, weight, FPKPA, and FPKPA asymmetry were categorised as above normal (+1 SD above the mean), normal (within 1 SD of the mean), and below normal (-1 SD below the mean) of the mean value for that risk factor in the cohort. For the subgroup analyses by sex, the categorised variables were calculated based on the mean values of each subgroup. BMI was categorised as healthy, low and overweight based on the cut-off values for adolescents.[34,35]

The statistical analyses were performed using SPSS (v 24, SPSS Inc., Chicago, Illinois, USA). To compare injured and uninjured subjects, the Mann–Whitney *U* test was used to test the variables that were not normally distributed (age, height, weight, BMI), the independent samples *t* test was used for the normally distributed variables (right FPKPA, left FPKPA), and the χ^2 test was used for the categorical variables (sex). The independent samples *t* test was used to investigate the differences in mean FPKPA between sexes. To analyse the differences in mean FPKPA between right and left leg and dominant and non-dominant leg, the paired samples *t* test was used. One-way ANOVA was used to investigate the differences in the FPKPA between age groups. The significance level was set at $P<0.05$.

A generalized linear mixed model for binary data with injury/no injury as the dependent variable was used to analyse the potential risk factors. The analyses were performed using each leg as a unit of analysis. Team and leg were used as random effects. First, the intrinsic factors were analysed using the univariate model. All the variables with a *P*-value <0.20 in the univariate analysis were entered into a multivariate model. If both the categorical and the continuous version of the same variable achieved $P<0.20$, the variable with a smaller *P*-value was entered into the multivariate model. In the multivariate analysis, the significance level was set at $P<0.05$.

RESULTS

A total of 558 players participated in the baseline SLS and completed the injury surveillance. Out of the 558 players, 445 were boys and 113 girls. Player characteristics by sex and age group are presented in Table 1. Dominant leg (preferred leg for kicking the ball), was right for 88% and left for 12% of the players. Two players did not name a preferred leg. During the follow-up, 285 acute lower extremity injuries were reported, out of which 142 (50%) were non-contact injuries. Out of the 558 players, 37% (n=205) were injured at least once. The majority of the injuries (41%) were minor (1 to 3 days of absence), however, moderate injuries (8 to 28 days of absence) were also common (25%) (Figure 3). The ankle was the most commonly injured body part (32% of all injuries), followed by the knee (20%) (Figure 4). The dominant leg was injured in 51% and non-dominant leg in 48% of the cases. In three slight injuries, the player was unable to report which leg was injured and these players were removed from the risk factor analysis. Number of injured legs by sex and age group are presented in Figure 5. A total of 40 players were unable to perform enough valid trials on either leg and 92 players only performed enough valid trials on one leg. When comparing the injured athletes to the uninjured, there were no differences in the mean values of age, height, weight, BMI, number of years playing football or the proportion of boys and girls.

Risk factors for acute lower extremity injuries

In the univariate analysis for the risk of a new acute lower extremity injury, the categorical weight and BMI and continuous height, weight and BMI achieved $P<0.20$ (Table 2). Continuous height and weight and categorical BMI were entered into the multivariate model based on the smaller *P*-value. In the multivariate analysis there were no associations between the variables and the risk of lower extremity injuries (Table 3).

In the subgroup analysis of boys, categorical height and weight and continuous height, weight and age achieved $P<0.20$. Categorical height and weight and continuous age were entered in to the multivariate analysis but were not associated with acute lower extremity injury (Table 3). Among girls, none of the variables achieved $P<0.20$ in the univariate analysis, therefore no multivariate analysis was performed. The univariate analyses for lower extremity injury for boys and girls are presented in supplementary material (Appendix tables 1–2).

Risk factors for acute non-contact lower extremity injuries

In the univariate analysis of new acute non-contact lower extremity injury risk in the entire cohort, low BMI and high FPKPA asymmetry achieved $P<0.20$ in the univariate analysis (Table 4). In the multivariate analysis, the analysed factors were not associated with non-contact injuries (Table 5).

For boys, low BMI and high FPKPA asymmetry were entered into the multivariate model but were not associated with non-contact injury (Table 5). For girls, categorised weight and ability to perform valid SLS test were entered into the multivariate model but were not associated with non-contact lower extremity injury (Table 5). Univariate analyses for a new non-contact lower extremity injury by sex are presented in supplementary material (Appendix tables 3–4).

Effects of age, sex and leg dominance on FPKPA

There was no difference in the mean FPKPA between boys and girls. There were significant differences in FPKPA between age groups among boys (F=3.09, $P=0.03$) and girls (F=4.22, $P=0.006$). Among boys, the FPKPA decreased as age increased. Among girls, the largest mean FPKPA was detected in the U12 age group. The oldest girls demonstrated best frontal plane knee control (mean FPKPA 12.2° $\pm$ 8.3°). The mean values for FPKPA by sex and age group for right, left, dominant and non-dominant leg are presented in Table 6.

There were significant differences in the mean FPKPA between the right and the left leg and the dominant and the non-dominant leg (Table 6). Among both sexes, the FPKPA was greater on the right leg compared to the left ($P<0.001$ for boys and for girls) and greater on the dominant compared to the non-dominant leg ($P<0.001$ for boys and $P=0.001$ for girls). When further analysed by age group, the differences were statistically significant in all age groups among boys and U11 girls.

DISCUSSION

Our study on a cohort of youth football players investigated the relationship between FPKPA and sustaining an acute lower extremity injury and non-contact lower extremity injury. We found no association between the FPKPA and future injuries.

FPKPA and the risk of lower extremity injury

In the current study, we found no association between the FPKPA during the SLS and future lower extremity injuries. In our previous study among older team sport athletes (mean age 15.7 $\pm$ 1.8 years), we detected a significant association between FPKPA and acute lower extremity injury and acute ankle injury: displaying high FPKPA was associated with a higher odds of injury.[29] The association between frontal plane knee control and the risk of injuries has not been previously studied in young, under 14-year-old athletes. Padua et al.[36] utilised another field-assessment test, the Landing Error Scoring System, to study the association between high-risk movement patterns and the risk of anterior cruciate ligament injury. Out of the cohort of 11 to 17-year-old football players, 25% were U13 players. The athletes who were injured during the follow-up demonstrated more high-risk movement patterns during the test than the uninjured players. However, none of the injured players were under 13-years-old. Generally in sports, the under 13-year-olds have a lower risk of injury than older adolescents[37] and in youth football, overall injury incidence increases along with age.[2,6,7,38] The lower risk of injury among the under 13-year-olds could be a possible explanation why no significant associations were detected between the analysed intrinsic factors and future injuries.

Leg dominance

Leg dominance is an imbalance in the strength and joint kinematics in the lower extremities[15] and it has been associated with an increased risk of lower extremity injuries.[39–41] We detected significantly greater FPKPA in the dominant leg, which suggests an imbalance in knee control between legs. However, displaying great FPKPA asymmetry was not associated with future injuries. Findings on the side-to-side differences must be interpreted with caution since the starting leg was not randomised. The SLS test was always performed on the right leg first, which was the dominant leg for most of the players. The learning effect could have influenced the results; it is possible that the SLS test was harder on the first attempts, which were done on the right leg. Therefore, the side-to-side asymmetry as a potential injury risk factor should be investigated further using randomisation of the starting leg.

Differences in FPKPA and injury risk between boys and girls

There was no difference in the mean FPKPA angle between boys and girls. This is in agreement with a prior study on adolescent SLS performance.[28] Agresta et al. (2016) evaluated frontal plane knee control during the SLS by visual assessment and detected no differences between sexes. In the current study, we detected differences in the FPKPA between age groups. Among boys, the frontal plane knee control improved along with age. Among girls, the relationship between age and FPKPA was not as clear. The oldest girls (U14) had the lowest mean FPKPA (12.0° $\pm$ 8.1°) in the study. The highest FPKPA among girls was measured in the U12 group (19.4° $\pm$ 11.2°). However, these findings on FPKPA may be somewhat limited by the small number of female subjects in this study; the girls' age groups consisted of 24 to 32 subjects.

Previous studies on youth football have reported no differences in injury risk between boys and girls.[2,6,42,43] We analysed sex as a potential risk factor in the entire cohort but detected no significant associations. In addition, separate risk factor analyses were performed for boys and girls. However, none of the analysed intrinsic factors were associated with injuries. Among the young football players, sex does not seem to affect lower extremity injury risk.

The single-leg squat test

The SLS test is used in clinical practice to assess frontal plane knee control. The visual assessment of frontal plane knee control correlates well with the FPKPA, when assessment if performed by experienced observer.[30] Previous studies on young athletes have shown that reduced frontal plane knee control is associated with higher risk of future injuries[29,39,44,45], although all the studies are not in agreement.[46] Since reduced knee control has been identified as an injury risk factor, using movement control tests to identify athletes who could reduce their injury risk by improving knee control seems sensible. In a previous study, different athletes were identified as having reduced knee control by the vertical drop jump and the SLS.[20] Therefore, it seems rational to use both, a jump-landing task and the SLS, to identify athletes with reduced knee control. When interpreting the results it must be kept in mind that sports injuries are multifactorial and movement control test results do not predict injuries but they do provide valuable information individual movement control and injury risk.

However, one factor to consider is the SLS test procedure. In the current study, the subjects were required to squat to 90° knee flexion. In some prior studies on SLS, the knee flexion angle has been determined at 60° [21,23–26,28], 90° [20,29,30] or the subjects to squat as far as possible while maintaining balance.[22,47] The procedure used here has been previously used among adults and older adolescents and it has been able to differentiate between the athletes.[20,29,30] In the present study, 40 players were not able to perform valid SLS trials on either leg and additional 92 players only performed enough valid trials on one leg. It is possible that among these young athletes, this test procedure could be too demanding for part of the population. The double-legged squat might be a more suitable tool to assess knee control among young athletes[48] and should be investigated further as potential, low level movement control test.

Strength and limitations

The weekly injury registration via text message was well received by the parents and the players and can be viewed as a strength of the study. The text messaging system made it possible for the players (or the parent) to report all musculoskeletal complaints. This can be considered more accurate than collecting injury data from coaches. The size of the cohort can be viewed as a strength of the current study. To our knowledge, this is the largest study describing SLS performance among adolescents and the first one to measure the FPKPA in the SLS in young subjects. However, the lack of exposure data can be viewed as a limitation since we are not able to analyse whether the players getting injured were exposed more or less than those not getting injured.

In the SLS protocol, the test was always performed on the right leg first. This can contribute to the significant differences detected between the right and left leg and dominant and non-dominant leg. This is considered a source of bias. We recommend randomising the starting leg in the SLS test procedure in future studies. In addition, the difficulty of the SLS test, as discussed previously, is a limitation to the study.

CONCLUSIONS

Frontal plane knee control is not associated with the risk of lower extremity injuries among young football players. There were significant side-to-side differences in frontal plane knee control between the dominant and non-dominant leg but displaying side-to-side asymmetry in FPKPA was not associated with future injuries.

PERSPECTIVES

Football is the most popular sport in the world. Young football players lose valuable training time due to injuries. There is a need to identify modifiable risk factors which are associated with a higher risk of lower extremity injuries. The results of this study indicate that among young football players, the single-leg squat test is not a suitable tool to assess the risk of future injuries.

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Conflicts of interest

The authors declare that they have no conflicts of interest relevant to the content of the study.

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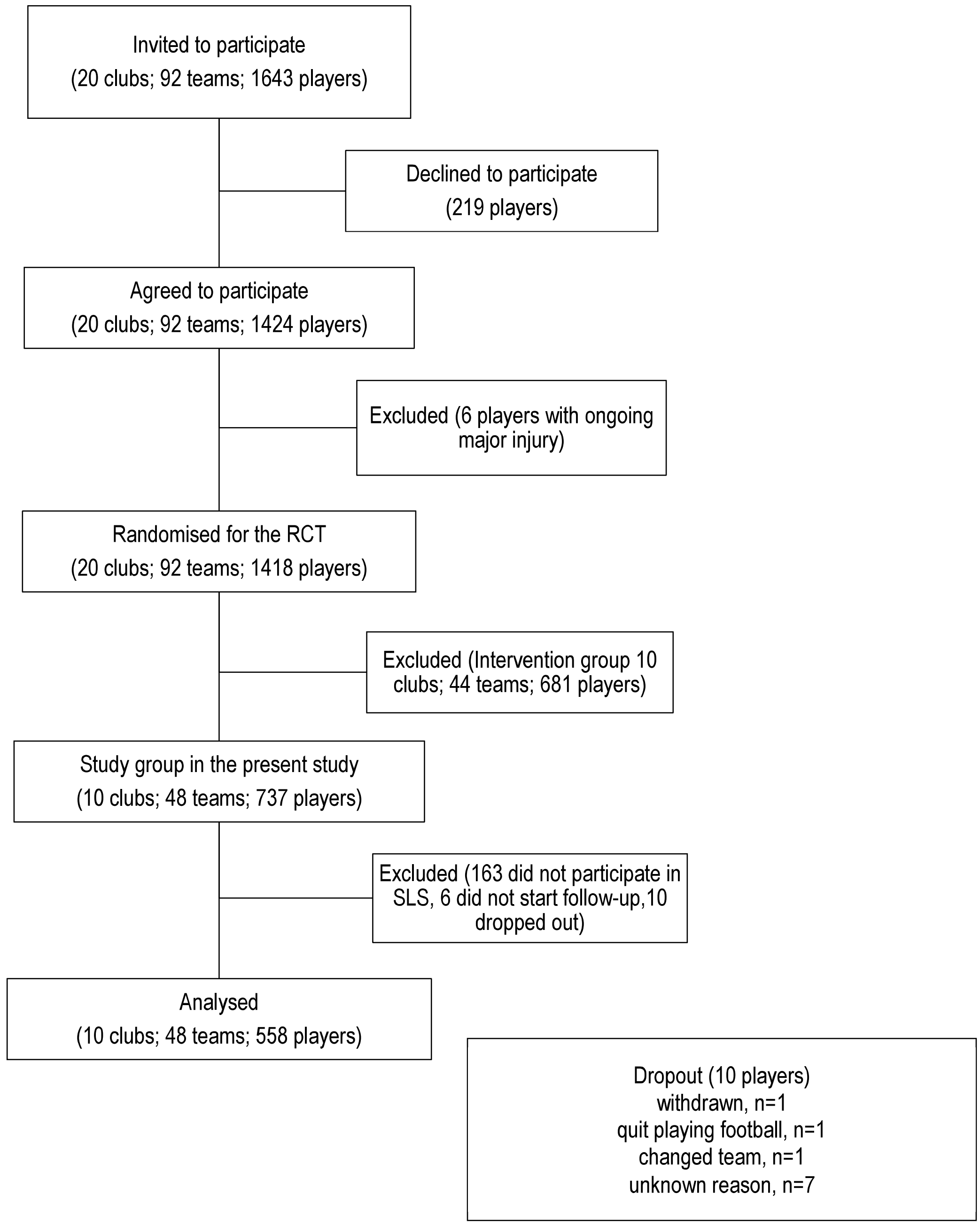

Figure 1. Number of players in each stage of the study

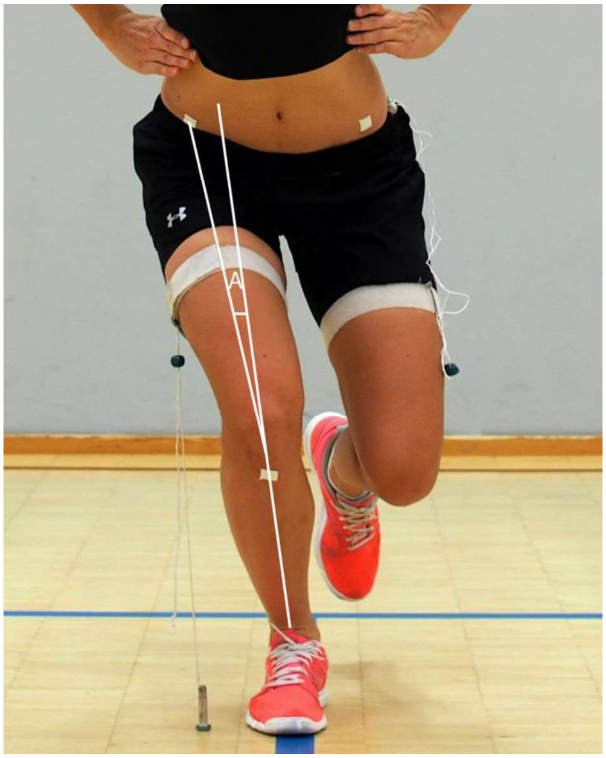

Figure 2. The frontal plane knee projection angle (A) measured during the single-leg squat

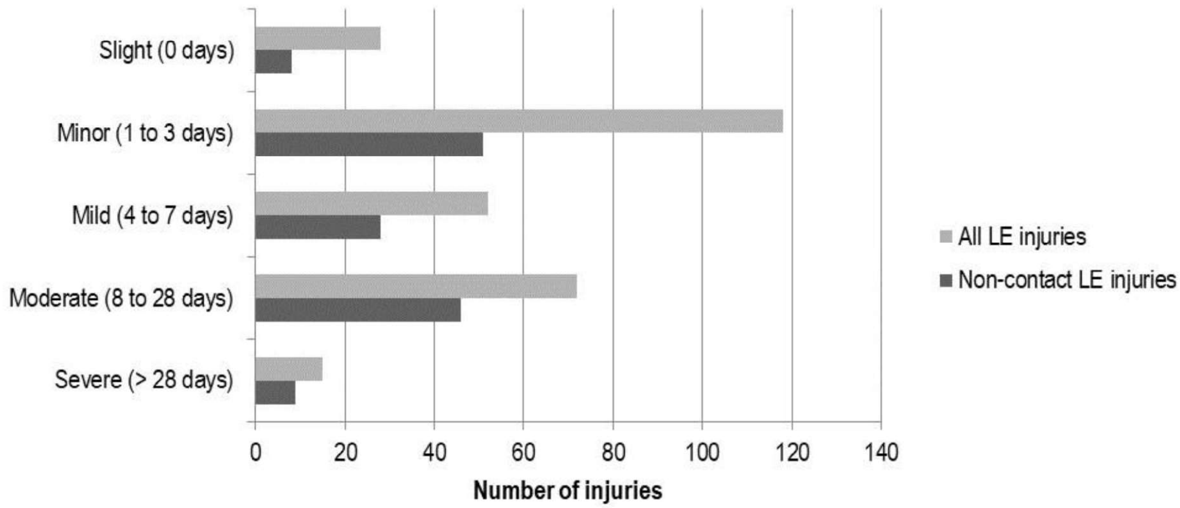

Figure 3. Number of acute lower extremity and acute non-contact lower extremity injuries by severity

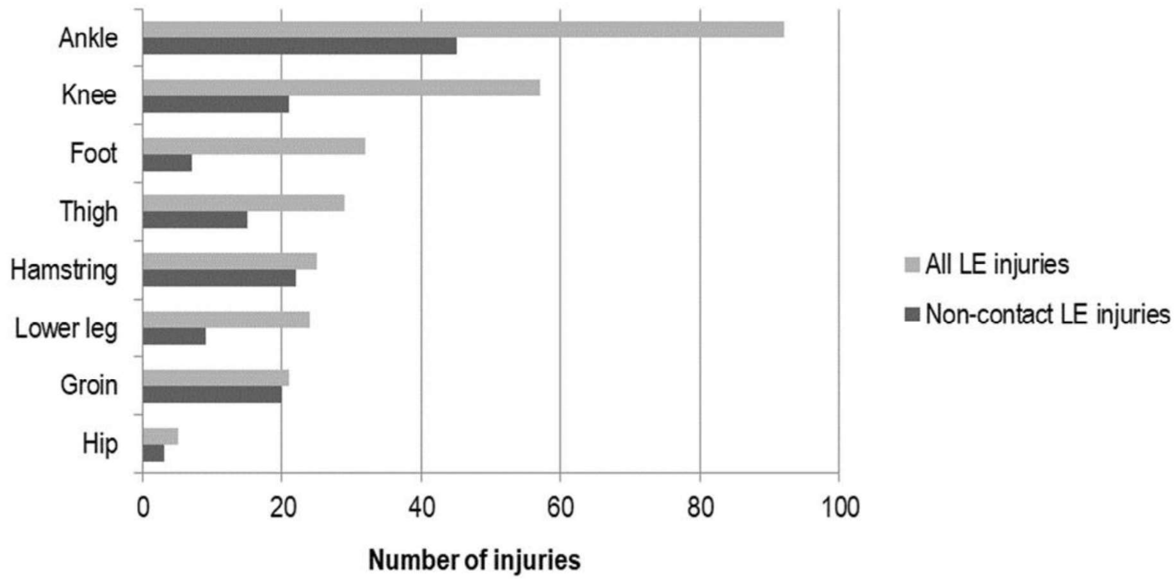

Figure 4. Number of acute lower extremity and acute non-contact lower extremity injuries according to anatomical locations

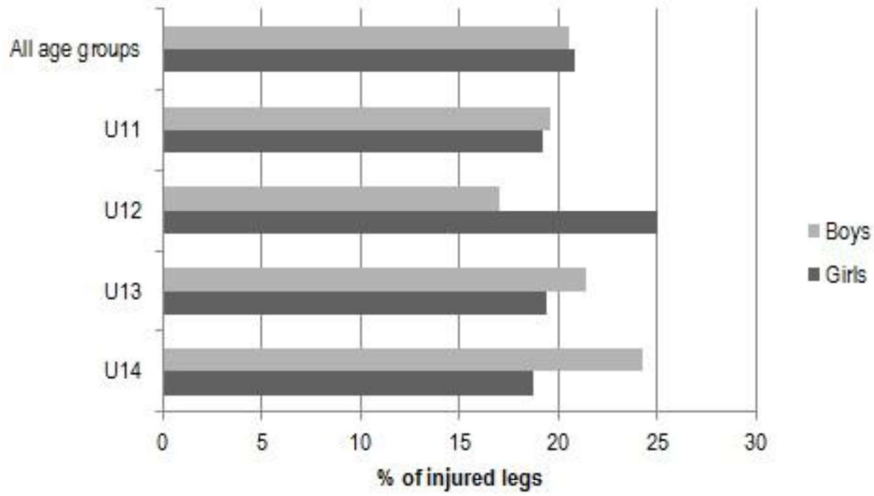

Figure 5. Proportion of injured legs for boys and girls and in each age group

Table 1. Baseline characteristics of the players (mean presented with standard deviation)

Age group	n	Height (cm)	Weight (kg)	BMI	Playing football (years)	FPKPA (°)
Boys	445	151.6 (9.9)	41.1 (8.7)	17.7 (1.9)	6.5 (1.7)	16.5 (12.6)
U11	117	143.3 (6.5)	34.9 (5.3)	16.9 (1.6)	5.1 (1.2)	17.6 (13.5)
U12	105	148.5 (6.5)	38.0 (5.1)	17.2 (1.5)	6.1 (1.2)	17.5 (13.5)
U13	116	154.0 (7.8)	43.3 (6.6)	17.8 (1.8)	6.8 (1.5)	17.0 (12.0)
U14	107	161.7 (8.3)	49.9 (9.2)	18.9 (2.2)	8.0 (1.3)	14.2 (11.5)
Girls	113	151.7 (9.2)	41.6 (7.7)	17.9 (1.7)	5.3 (1.6)	15.4 (10.7)
U11	26	140.5 (4.1)	33.1 (3.9)	16.7 (1.5)	4.2 (1.5)	15.0 (9.8)
U12	32	149.1 (6.4)	39.9 (5.8)	17.9 (1.4)	5.0 (1.0)	19.2 (11.3)
U13	31	157.3 (5.9)	45.6 (5.9)	18.3 (1.6)	5.7 (1.5)	14.2 (11.4)
U14	24	159.6 (5.9)	47.8 (5.3)	18.7 (1.5)	6.2 (1.8)	12.2 (8.3)

BMI=body mass index, FPKPA=frontal plane knee projection angle

Table 2. Univariate analyses of the potential risk factor for acute lower extremity injuries. Odds ratios (OR) presented with 95% confidence interval (CI). N refers to number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	P value
Categorical variables				
Boy	884 (183)	1		
Girl	226 (47)	0.94	0.63 to 1.40	0.75
Age, intermediate	650 (133)	1		
Age, low (<10.8 years)	236 (46)	0.93	0.64 to 1.35	0.70
Age, high (>13.2 years)	224 (51)	1.13	0.78 to 1.63	0.51
Height, intermediate	726 (152)	1		
Height, low (<142.3 cm)	186 (33)	0.81	0.53 to 1.23	0.32
Height, high (>161.1 cm)	172 (40)	1.13	0.76 to 1.68	0.56
Weight, intermediate	702 (148)	1		
Weight, low (<33.9 kg)	204 (34)	0.75	0.49 to 1.13	0.16 *
Weight, high (>49.3 kg)	178 (43)	1.17	0.79 to 1.73	0.43
BMI, healthy	984 (211)	1		
BMI, low	58 (7)	0.53	0.24 to 1.19	0.12 *
BMI, overweight	40 (7)	0.83	0.36 to 1.92	0.67
FPKPA, intermediate	622 (126)	1		
FPKPA, low (<4.0°)	154 (36)	1.19	0.78 to 1.82	0.42
FPKPA, high (>28.4°)	163 (34)	1.03	0.67 to 1.58	0.90
Able to perform valid SLS	938 (196)	1		
Unable to perform valid SLS	162 (31)	0.90	0.59 to 1.38	0.63
FPKPA asymmetry, intermediate	574 (124)	1		
FPKPA asymmetry, low (<2.6°)	132 (25)	0.86	0.53 to 1.39	0.54
FPKPA asymmetry, high (>18.8°)	148 (28)	0.84	0.53 to 1.33	0.46
Continuous variables				
Age (years)	1110 (230)	1.08	0.96 to 1.23	0.22
Height (cm)	1084 (225)	1.01	1.00 to 1.03	0.15 *
Weight (kg)	1082 (225)	1.02	1.00 to 1.03	0.08 *
BMI	1082 (225)	1.05	0.98 to 1.14	0.19 *
FPKPA (°)	938 (196)	1.00	0.99 to 1.01	0.95
FPKPA asymmetry (°)	898 (164)	1.00	0.98 to 1.03	0.67

BMI=body mass index, FPKPA=frontal plane knee projection angle, SLS=single-leg squat

Table 3. Multivariate analyses of the potential risk factors for all acute lower extremity injuries for all subjects and boys. Adjusted odds ratios (OR) presented with 95% confidence interval (CI). The variables achieving P<0.20 in univariate analyses were analysed. N refers to number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	*P* value
All subjects				
Height (cm)	1084 (225)	1.00	0.96 to 1.04	0.96
Weight (kg)	1082 (225)	1.02	0.97 to 1.06	0.46
BMI, healthy	984 (211)	1		
BMI, low	58 (7)	0.60	0.25 to 1.39	0.23
BMI, overweight	40 (7)	0.66	0.245to 1.74	0.40
Boys				
Height, intermediate	614 (128)	1		
Height, low (<141.7 cm)	128 (19)	0.86	0.44 to 1.68	0.65
Height, high (>161.5 cm)	126 (31)	1.13	0.59 to 2.14	0.72
Weight, intermediate	636 (133)	1		
Weight, low (<32.4 kg)	104 (14)	0.65	0.31 to 1.34	0.24
Weight, high (>49.8 kg)	128 (31)	1.10	0.58 to 2.07	0.79
Age (years)	884 (183)	1.01	0.85 to 1.21	0.89

BMI=body mass index

Table 4. Univariate analyses of the potential risk factor for acute non-contact lower extremity injuries. Odds ratios (OR) presented with 95% confidence interval (CI). N refers to number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	*P* value	
Categorical variables					
Boy	884 (95)	1			
Girl	226 (28)	1.15	0.72 to 1.83	0.57	
Age, intermediate	650 (69)	1			
Age, low (<10.8 years)	236 (27)	1.08	0.67 to 1.73	0.75	
Age, high (>13.2 years)	224 (27)	1.14	0.71 to 1.83	0.59	
Height, intermediate	726 (78)	1			
Height, low (<142.3 cm)	186 (20)	0.99	0.59 to 1.68	0.98	
Height, high (>161.1 cm)	172 (22)	1.19	0.72 to 1.98	0.50	
Weight, intermediate	702 (75)	1			
Weight, low (<33.9 kg)	204 (22)	1.00	0.601to 1.66	0.99	
Weight, high (>49.3 kg)	178 (23)	1.22	0.74 to 2.01	0.42	
BMI, healthy	984 (116)	1			
BMI, low	58 (2)	0.27	0.07 to 1.13	0.07	*
BMI, overweight	40 (2)	0.41	0.10 to 1.71	0.22	
FPKPA, intermediate	6272(66)	1			
FPKPA, low (<4.0°)	154 (17)	1.07	0.60 to 1.89	0.82	
FPKPA, high (>28.4°)	163 (19)	1.09	0.63 to 1.87	0.77	
Able to perform valid SLS	938 (102)	1			
Unable to perform valid SLS	162 (18)	1.04	0.61 to 1.76	0.90	
FPKPA asymmetry, intermediate	574 (69)	1			
FPKPA asymmetry, low (<2.6°)	132 (17)	1.10	0.62 to 1.94	0.75	
FPKPA asymmetry, high (>18.8°)	148 (12)	0.65	0.34 to 1.23	0.18	*
Continuous variables					
Age (years)	1110 (123)	1.02	0.87 to 1.19	0.85	
Height (cm)	1084 (120)	1.00	0.98 to 1.02	0.92	
Weight (kg)	1082 (120)	1.00	0.98 to 1.03	0.79	
BMI	1082 (120)	1.01	0.91 to 1.12	0.87	
FPKPA (°)	938 (102)	1.00	0.98 to 1.02	0.92	
FPKPA asymmetry (°)	798 (89)	0.99	0.96 to 1.02	0.43	

BMI=body mass index, FPKPA=frontal plane knee projection angle, SLS=single-leg squat

Table 5. Multivariate analyses of potential risk factors for non-contact lower extremity injuries for all subjects, boys and girls. Adjusted odds ratios (OR) presented with 95% confidence interval (CI). The variables achieving P<0.20 in univariate analyses were analysed. N refers to number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	*P* value
All subjects				
BMI, healthy	984 (116)	1		
BMI, low	58 (2)	0.4	0.09 to 1.70	0.21
BMI, overweight	40 (2)	0.00	0.00 to 0.00	0.99
FPKPA asymmetry, intermediate	574 (69)	1		
FPKPA asymmetry, low (<2.6°)	132 (17)	1.13	0.64 to 2.02	0.68
FPKPA asymmetry, high (>18.8°)	148 (12)	0.679	0.35 to 1.30	0.24
Boys				
FPKPA asymmetry, intermediate	450 (53)	1		
FPKPA asymmetry, low (<2.5°)	98 (13)	1.13	0.60 to 2.23	0.67
FPKPA asymmetry, high (>19.5°)	102 (7)	0.59	0.26 to 1.35	0.21
BMI, healthy	784 (88)	1		
BMI, low	48 (2)	0.6	0.14 to 2.59	0.49
BMI, overweight	34 (2)	0.00	0.00 to 0.00	0.98
Girls				
Weight, intermediate	134 (13)	1		
Weight, low (<34.0 kg)	40 (8)	2.50	0.93 to 6.71	0.07
Weight, high (>49.2 kg)	42 (7)	1.43	0.48 to 4.31	0.52
Able to perform valid SLS	212 (23)	1		
Unable to perform valid SLS	11 (3)	2.93	0.67 to 12.78	0.15

BMI=body mass index, FPKPA=frontal plane knee projection angle, SLS=single-leg squat

Table 6. Mean frontal plane knee projection angles (FPKPA) by sex and age group. P values are presented for the comparisons of right and left leg and dominant and non-dominant leg FPKPA.

Sex and age group	Mean FPKPA right leg (SD)	Mean FPKPA left leg (SD)	*P* value	Mean FPKPA dominant leg (SD)	Mean FPKPA non-dominant leg (SD)	*P* value
Boys	19.6 (12.2)	13.4 (12.3)	<0.001	19.2 (12.1)	13.8 (12.6)	<0.001
U11	20.1 (13.2)	14.9 (13.5)	<0.001	19.4 (13.2)	15.6 (13.8)	0.004
U12	18.8 (13.3)	16.2 (13.6)	0.04	19.1 (13.1)	15.8 (13.8)	0.02
U13	21.1 (11.7)	12.7 (10.7)	<0.001	20.8 (11.4)	13.2 (11.3)	<0.001
U14	18.2 (10.7)	10.0 (10.7)	<0.001	17.3 (10.9)	10.8 (11.1)	<0.001
Girls	17.2 (9.5)	13.5 (11.5)	<0.001	17.1 (10.2)	13.6 (10.9)	0.001
U11	19.0 (7.4)	10.8 (10.3)	<0.001	19.0 (7.4)	10.8 (10.3)	<0.001
U12	19.9 (10.0)	18.5 (12.6)	0.69	20.6 (11.3)	17.8 (11.3)	0.21
U13	15.9 (10.2)	12.6 (12.5)	0.06	15.1 (11.1)	13.4 (11.9)	0.24
U14	13.3 (9.1)	11.1 (7.5)	0.29	13.0 (8.5)	11.5 (8.3)	0.49

FPKPA=frontal plane knee projection angle, SD= standard deviation

SUPLEMENTARY FILES

Appendix table 1. Univariate odds ratios (OR) for new acute lower extremity injury for boys presented with 95% confidence interval (CI). N refers to the number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	*P* value	
Categorical variables					
Age, intermediate	502 (100)	1			
Age, low (<10.8 years)	200 (40)	0.99	0.65 to 1.49	0.95	
Age, high (>13.2 years)	182 (43)	1.23	0.82 to 1.85	0.33	
Height, intermediate	614 (128)	1			
Height, low (<141.7 cm)	128 (19)	0.67	0.39 to 1.14	0.14	*
Height, high (>161.5 cm)	126 (31)	1.23	0.78 to 1.93	0.38	
Weight, intermediate	636 (133)	1			
Weight, low (<32.4 kg)	104 (14)	0.58	0.32 to 1.05	0.07	*
Weight, high (>49.8 kg)	128 (31)	1.22	0.78 to 1.91	0.39	
BMI, healthy	784 (165)	1			
BMI, low	48 (7)	0.72	0.32 to 1.64	0.43	
BMI, overweight	34 (6)	0.94	0.38 to 2.33	0.89	
FPKPA, intermediate	470 (97)	1			
FPKPA, low (<3.9°)	121 (29)	1.20	0.74 to 1.93	0.46	
FPKPA, high (>29.1°)	136 (28)	0.98	0.61 to 1.58	0.94	
Able to perform valid SLS	726 (154)	1			
Unable to perform valid SLS	151 (28)	0.85	0.54 to 1.34	0.49	
FPKPA asymmetry, intermediate	450 (98)	1.00			
FPKPA asymmetry, low (<2.5°)	98 (19)	0.85	0.49 to 1.47	0.56	
FPKPA asymmetry, high (>19.5°)	102 (18)	0.76	0.43 to 1.33	0.33	
Continuous variables					
Age (years)	884 (183)	1.12	0.97 to 1.28	0.12	*
Height (cm)	868 (178)	1.01	1.00 to 1.03	0.16	*
Weight (kg)	866 (178)	1.02	1.00 to 1.04	0.09	*
BMI	866 (178)	1.05	0.97 to 1.15	0.23	
FPKPA (°)	726 (154)	1.00	0.99 to 1.02	0.98	
FPKPA asymmetry (°)	610 (126)	1.01	0.98 to 1.03	0.62	

BMI=body mass index, FPKPA=frontal plane knee projection angle, SLS=single-leg squat

Appendix table 2. Univariate odds ratios (OR) for new acute lower extremity injury for girls presented with 95% confidence interval (CI). N refers to the number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	*P* value
Categorical variables				
Age, intermediate	132 (29)	1		
Age, low (<10.9 years)	48 (9)	0.82	0.35 to 1.89	0.64
Age, high (>13.1 years)	46 (9)	0.91	0.39 to 2.12	0.83
Height, intermediate	136 (30)	1		
Height, low (<142.5 cm)	44 (10)	1.02	0.45 to 2.31	0.96
Height, high (>160.9 cm)	36 (7)	0.84	0.33 to 2.11	0.70
Weight, intermediate	134 (26)	1		
Weight, low (<34.0 kg)	40 (10)	1.36	0.59 to 3.15	0.47
Weight, high (>49.2 kg)	42 (11)	1.45	0.64 to 3.28	0.37
BMI, healthy	200 (46)	1		
BMI, low	10 (0)	0.10	0.00 to 4.13	0.22
BMI, overweight	6 (1)	0.66	0.07 to 5.86	0.71
FPKPA, intermediate	145 (29)	1		
FPKPA, low (<4.7°)	35 (7)	0.97	0.39 to 2.49	0.97
FPKPA, high (>26.1°)	32 (6)	0.91	0.34 to 2.42	0.84
Able to perform valid SLS	212 (42)	1		
Unable to perform valid SLS	11 (3)	1.50	0.38 to 5.95	0.56
FPKPA asymmetry, intermediate	132 (28)	1.00		
FPKPA asymmetry, low (<2.6°)	34 (6)	0.86	0.32 to 2.30	0.76
FPKPA asymmetry, high (>18.8°)	38 (8)	0.99	0.41 to 2.42	0.99
Continuous variables				
Age (years)	226 (47)	0.95	0.71 to 1.28	0.75
Height (cm)	216 (47)	1.01	0.97 to 1.04	0.76
Weight (kg)	216 (47)	1.01	0.97 to 1.06	0.52
BMI	216 (47)	1.09	0.89 to 1.33	0.40
FPKPA (°)	212 (42)	1.00	0.97 to 1.03	0.89
FPKPA asymmetry (°)	188 (38)	1.00	0.95 to 1.05	0.92

BMI=body mass index, FPKPA=frontal plane knee projection angle, SLS=single-leg squat

Appendix table 3. Univariate odds ratios (OR) for new acute non-contact lower extremity injury for boys presented with 95% confidence interval (CI). N refers to the number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	*P* value	
Categorical variables					
Age, intermediate	502 (49)	1			
Age, low (<10.8 years)	200 (23)	1.20	0.71 to 2.03	0.50	
Age, high (>13.2 years)	182 (23)	1.32	0.78 to 2.25	0.30	
Height, intermediate	614 (64)	1			
Height, low (<141.7 cm)	128 (11)	0.82	0.42 to 1.60	0.55	
Height, high (>161.5 cm)	126 (17)	1.33	0.75 to 2.36	0.34	
Weight, intermediate	636 (67)	1			
Weight, low (<32.4 kg)	104 (9)	0.80	0.39 to 1.66	0.55	
Weight, high (>49.8 kg)	128 (16)	1.21	0.68 to 2.17	0.52	
BMI, healthy	784 (88)	1			
BMI, low	48 (2)	0.35	0.08 to 1.48	0.16	*
BMI, overweight	34 (2)	0.52	0.12 to 2.22	0.38	
FPKPA, intermediate	470 (52)	1			
FPKPA, low (<3.9°)	121 (13)	0.95	0.50 to 1.82	0.89	
FPKPA, high (>29.1°)	136 (14)	0.92	0.49 to 1.71	0.78	
Able to perform valid SLS	726 (79)	1			
Unable to perform valid SLS	151 (15)	0.91	0.51 to 1.63	0.75	
FPKPA asymmetry, intermediate	450 (53)	1			
FPKPA asymmetry, low (<2.5°)	98 (13)	1.13	0.59 to 2.17	0.71	
FPKPA asymmetry, high (>19.5°)	102 (7)	0.56	0.24 to 1.27	0.16	*
Continuous variables					
Age (years)	884 (95)	1.08	0.90 to 1.29	0.41	
Height (cm)	868 (92)	1.01	0.99 to 1.03	0.55	
Weight (kg)	866 (92)	1.01	0.98 to 1.03	0.50	
BMI	866 (92)	1.02	0.92 to 1.15	0.69	
FPKPA (°)	726 (79)	1.00	0.98 to 1.02	0.90	
FPKPA asymmetry (°)	610 (66)	0.98	0.96 to 1.02	0.30	

BMI=body mass index, FPKPA=frontal plane knee projection angle, SLS=single-leg squat

Appendix table 4. Univariate odds ratios (OR) for new acute non-contact lower extremity injury for girls presented with 95% confidence interval (CI). N refers to the number of legs in the analysis.

Intrinsic factors	n (injured)	OR	95% CI	*P* value	
Categorical variables					
Age, intermediate	132 (17)	1			
Age, low (<10.9 years)	48 (7)	1.15	0.44 to 2.99	0.77	
Age, high (>13.1 years)	46 (4)	0.68	0.21 to 2.15	0.51	
Height, intermediate	136 (16)	1			
Height, low (<142.5 cm)	44 (8)	1.64	0.65 to 4.17	0.30	
Height, high (>160.9 cm)	36 (4)	0.92	0.29 to 2.97	0.89	
Weight, intermediate	134 (13)	1			
Weight, low (<34.0 kg)	40 (8)	2.29	0.87 to 6.04	0.09	*
Weight, high (>49.2 kg)	42 (7)	1.83	0.67 to 4.98	0.23	
BMI, healthy	200 (28)	1			
BMI, low	10 (0)	0.00	0.00 to 0.00	1.00	
BMI, overweight	6(0)	0.00	0.00 to 0.00	1.00	
FPKPA, intermediate	145 (16)	1			
FPKPA, low (<4.7°)	35 (3)	0.77	0.21 to 2.76	0.69	
FPKPA, high (>26.1°)	32 (4)	1.13	0.35 to 3.64	0.84	
Able to perform valid SLS	212 (23)	1			
Unable to perform valid SLS	11 (3)	3.09	0.76 to 12.6	0.12	*
FPKPA asymmetry, intermediate	132 (16)	1			
FPKPA asymmetry, low (<2.6°)	34 (4)	1.04	0.32 to 3.36	0.95	
FPKPA asymmetry, high (>18.8°)	38 (5)	1.10	0.37 to 3.24	0.86	
Continuous variables					
Age (years)	226 (28)	0.79	0.55 to 1.14	0.20	
Height (cm)	216 (28)	0.98	0.94 to 1.02	0.34	
Weight (kg)	216 (28)	0.98	0.93 to 1.03	0.43	
BMI	216 (28)	0.94	0.74 to 1.20	0.64	
FPKPA (°)	212 (23)	1.00	0.97 to 1.05	0.83	
FPKPA asymmetry (°)	188 (23)	1.01	0.96 to 1.08	0.64	

BMI=body mass index, FPKPA=frontal plane knee projection angle, SLS=single-leg squat