A prospective investigation to evaluate risk factors for lower extremity injury risk in male youth soccer players

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ABSTRACT

There is an inherent risk of injury in male youth football; however, pertinent risk factors for injury have yet to be examined. This study used a prospective cohort design with 357 elite male youth football players (aged 10-18 years) assessed during the pre-season period and then monitored during the season recording all non-contact lower extremity injuries. Screening tests included: single leg hop for distance (SLHD); 75% of maximum hop and stick (75%Hop); single leg countermovement jump (SLCMJ); and the tuck jump assessment (TJ). Players were divided into sub-groups based on chronological age. SLCMJ peak landing vertical ground reaction force (pVGRF) asymmetry was the most prominent risk factor (U11-U12's, OR 0.90, $p = 0.04$; and U15-U16's, OR 0.91, $p < 0.001$). Maturational offset (OR 0.58, $p = 0.04$), lower right leg SLCMJ pVGRF relative to body weight (OR 0.36, $p = 0.03$) and advanced chronological age (OR 3.62, $p = 0.04$) were also significantly associated with heightened injury risk in the U13-U14's, U15-U16's and U18's respectively. Univariate analyses showed combinations of anthropometric and movement screening risk factors were associated with heightened risk of lower extremity injury; however, there was variability across the different chronological age groups. Greater SLCMJ pVGRF asymmetry, lower right leg SLCMJ pVGRF %BW, later maturation and advanced chronological age are potential risk factors for injury in elite male youth football players, although the strength of these relationships were often low to moderate. In addition, risk factors are likely to change at different stages of development.

Key Terms: Injury, screening, youth, football

INTRODUCTION

Elite male youth football players display an inherent risk of lower extremity injury (22, 36) and should be considered a target group for injury prevention (44). Prospective assessment of modifiable risk factors is critical to aid in the identification of injury risk prior to their occurrence and the development of targeted strategies for risk reduction. Neuromuscular control may be the most modifiable risk factor (15, 17) and has previously been associated with injury, albeit in adult and female athletes (18, 31, 32, 33, 45. Analysis of injury risk factors in elite male youth football players is warranted due to the high frequency of injuries reported in this cohort (20, 22, 36, 37, 38).

There is a paucity of prospective studies to examine risk factors for non-contact lower extremity injuries in elite male youth football players. Only one study has assessed baseline measures of neuromuscular control and prospectively tracked injuries throughout the course of a season in male youth football players (33). Altered landing kinematics were reported in players who subsequently sustained an anterior cruciate ligament (ACL) injury versus non-injured controls. However, only one injury was sustained by a male player, and the analysis was restricted to ACL injuries only. Due to the high incidence of knee and ankle ligament injuries in this cohort (6, 36, 48), further assessments of landing kinetics and kinematics are warranted with male youth football players to determine their sensitivity for identifying players who subsequently sustain a lower extremity injury.

Due to the multi-factorial nature of commonly experienced injuries in football, risk factors should be examined using a variety of tests (26, 37, 38). This approach has shown increased sensitivity in the identification of individuals who display aberrant movement patterns following injury (4). A multi-factorial model designed to indicate injury risk including measures of landing kinetics and kinematics has recently been validated in junior athletes, with

those who sustained an injury demonstrating lower cumulative performance scores than their non-injured counterparts (25). The validity of a practically viable testing battery has not been examined in male youth football players, despite its potential ability to aid in the identification of "at risk" athletes for lower extremity injury. Therefore, the aim of this study was to examine if individual tests included in a field-based screening battery which measure either landing kinetics or kinematics are associated with lower extremity injury in elite male youth football players.

MATERIALS AND METHODS

Participants

Three hundred and fifty-six elite male youth football players from the academies of six professional English Premier League and Championship football clubs volunteered to take part. Descriptive statistics for anthropometric measures and predicted maturational status (years from peak height velocity) are provided in table 1. Parental consent, participant assent and physical activity readiness questionnaires were collected prior to the commencement of testing. Physical activity readiness questionnaires were used to determine if each participant's health status was appropriate and that there were no significant physical reasons as to why they should not partake in the research project. Inclusion criteria required players to be free from illness and injury at the time of base-line testing and participating regularly in football training and competitions in a professional academy football club operating in accordance with the procedures as set out by the English Premier League's Elite Player Performance Plan. Twenty-five players across the six academies included in the current study did not participate in base-line screening due to injury or illness and these players were subsequently removed from the analysis. None of the players reported injuries at the time of base-line testing and all were

participating regularly in football training and competitions. Ethical approval was granted by the institutional ethics committee in accordance with the declaration of Helsinki.

Table 1 Anthropometrics (mean ± SD) for participants per sub-group

Age Group	N	Age (yrs.)	Mass (kg)	Height (cm)	BMI (kg/m²)	Leg Length (cm)	Maturational Offset
U11-U12	80	11.6 ± 0.8	39.4 ± 5.6	146.5 ± 6.8	18.3 ± 2.3	77.4 ± 5.1	-2.4 ± 0.6
U13-U14	114	13.6 ± 0.8	48.6 ± 8.6	160.5 ± 9.2	18.7 ± 1.8	84.8 ± 7.6	-0.5 ± 0.9
U15-U16	118	15.7 ± 0.7	63.1 ± 8.0	173.8 ± 0.1	20.8 ± 1.6	91.6 ± 5.4	1.4 ± 0.6
U18	44	17.5 ± 5.7	72.8 ± 5.7	178.5 ± 0.1	22.8 ± 1.7	91.2 ± 4.2	3.0 ± 0.7

Experimental Design

A prospective cohort design was used. Following a familiarization session, players were required to attend their respective clubs training ground during the pre-season period (July) to undertake a comprehensive field-based screening battery that has shown to be reliable in elite male youth football players (37, 38). Players were then tracked for a period of 10 months (August to June) during the 2014-2015 season to prospectively record all injuries sustained in football training and competitions at their respective clubs.

Injury Reporting

Injury reporting: Non-contact, lower extremity injuries sustained were diagnosed, classified and prospectively recorded by each clubs' respective medical personnel in accordance with methods outlined previously and the regulations set out by the Premier League's Elite Player Performance Plan (31, 36). Injuries were documented if they occurred during football-related activities and if the player was subsequently unable to participate in training or competition for a minimum of 48 hours following the incident, not including the day of injury (36). *Injury mechanism* was defined, whereby a contact or non-contact injury was indicated when an incident with clear contact or collision from another player, the ball or another object either did, or did not, occur respectively. Players were classified as injured until the medical staff (chartered physiotherapists) of their respective clubs deemed they were fit to resume full training. *Injury severity* was classified based on the number of days missed including: slight (2 - 3 days), minor (4 - 7 days), moderate (1 - 4 weeks) and severe (> 4 weeks). Due to the confounding effects of previous injuries (1, 16, 21), only the first incident experienced by each player during the season was used in the subsequent analysis (31).

Risk Factor Screening Tests

Biological Maturity: Stage of biological maturation was assessed using a previously validated and non-invasive regression equation (27), comprising measures of chronological age (yrs), body mass (kg), standing height (cm) and sitting height (cm).

Tuck jump assessment (TJA): 10 repeated tuck jumps were performed in place and the technique of each participant was visually graded to assess for the presence of dynamic knee valgus (41). To impart a further level of analysis, valgus angles were subjectively classified as either 'minor' (<10°), 'moderate' (10-20°), or 'severe' (>20°) and scored as follows: 0 = no valgus; 1 = minor; 2 = moderate; 3 = severe based on previous recommendations (41). If a deficit was present on two or more occasions it was marked with the appropriate score (29). Two-dimensional video capture was used to record each trial and participants were graded retrospectively. Kinematic data were collected at 50 Hz using a high-definition video camera (Samsung, New Jersey, USA) positioned in the frontal plane at a height of 0.70 m, and a triangulated distance of five meters from the capture area. Interrater reliability of this method has been reported previously (ICC = 0.90) (39, 41).

Single leg hop for distance (SLHD): Hop distances were recorded using a standard tape measure marked out on the floor. Subjects began by standing on the designated test leg with their toe on the marked starting line, the hip of the free leg flexed at 90° to minimize contralateral propulsion, and their hands on their hips. Instructions were to hop forward as far as possible, landing on the same leg and then stick the landing and hold for three seconds (13). Three trials were performed on each leg and the distance in line with the heel was recorded to the nearest 0.1 cm using a ruler stick.

Single leg 75% horizontal hop and stick (75%Hop): A tape measure was marked out on a horizontal line with the 0 cm mark positioned in line with the centre of a force plate (Pasco, Roseville, California, USA). Participants began by standing in line with the force plate on the designated test leg, hands on their hips, and toe in line with a distance marker on the tape

measure representing 75% of their predetermined SLHD score. Instructions were to hop forward onto the force plate, land on the same leg and stick the landing, holding the position for seven seconds. Three trials were performed on each leg.

Single leg countermovement jump (SLCMJ): Participants began standing on a force plate (Pasco, Roseville, California, USA) in a unilateral stance with their hands on their hips and the opposite hip flexed at 90° to minimize contributions from the contralateral leg. Instructions were to jump as high as possible using a countermovement by dropping into a quarter squat and then immediately triple extending at the ankle, knee and hip in an explosive concentric action. On landing, subjects were required to stick and hold the landing for a period of seven seconds remaining as still as possible. Three trials were performed on each leg.

Force plate variables: Kinetic data captured from the force platform included pVGRF following ground contact. Acceptable reliability for these measures and test protocols has been shown previously in elite male youth football players (40). For the 75%Hop, initial contact was defined as the point when vertical ground reaction force first exceeded 10 N. In the SLCMJ, the same criteria were used to determine initial contact following the preceding propulsive and flight time phases. In both tests, pVGRF was normalized to body weight. All data were recorded at a sampling rate of 1000 Hz and filtered through a fourth-order Butterworth filter with a cut-off frequency of 18 Hz.

Asymmetry: To quantify asymmetry, the percentage difference between the highest and lowest performing limb was calculated for all tests as previously suggested (42). The value obtained was expressed as the absolute percentage of performance achieved using the higher performing limb as the reference (equation 1).

Asymmetry % =ABS((lowest performing limb - highest performing limb) /

highest performing limb * 100)

% of Performance achieved = 100 - % Asymmetry ABS = Absolute

[equation 1]

Statistical analysis

Descriptive statistics for each test were calculated as mean ± *sd*. Firstly, a univariate binary logistic regression of each injury risk factor was used to examine the relationships of each test with lower extremity injury. This step was also adopted to reduce the number of outcome variables and reduce the error degree of freedom. Neuromuscular and anatomical risk factors that displayed a p value < 0.1 were considered for further analysis. Secondly, tests of multicollinearity were completed for the risk factors identified in step 1 and was confirmed where the variance inflation factor was > 10 (28). In such cases, variables identified with the most clinical significance were further investigated in a multivariate binary logistic regression. The odds ratio (OR) for each risk factor in the univariate and multivariate analyses was calculated, with 95% confidence intervals (CI). A p value < 0.05 was indicative of a significant effect. Participants were grouped by chronological age using the following sub-categories: U11 and U12, U13 and U14, U15 and U16, and U18s.

RESULTS

Injury Reporting

Ninety-nine players sustained a non-contact lower extremity injury during the data collection period. The knee was the most frequently injured anatomical site (31%) followed by the ankle (19%). There were a high proportion of strain type injuries (35%), with ligament (17%) and growth/overuse (14%) the most prevalent diagnosis thereafter. Half of the injuries (50%) were moderate (1-4 weeks), however severe injuries (> 4 weeks absent) were also frequently reported (32%).

Relationship between injury risk factors and injury occurrence per chronological age group

U11 and U12 players

Eighteen injuries were sustained from a sample of eighty players in these two age groups. Injured players were older, corresponding to a 64% heightened risk per *sd* increase; however, this was not statistically significant (table 2).

Table 2. Anthropometrics (mean ± SD) for participants for injured and non-injured players

Anthropometrics	Injured Players	Non-injured Players	Odds Ratio	*P* Value
U11-U12 age groups				
Age	11.8 ± 0.5	11.5 ± 0.8	1.64 (0.78 - 3.42)	0.19
Height	145.8 ± 6.1	146.6 ± 7.0	0.98 (0.91 - 1.06)	0.66
Weight	38.9 ± 6.4	39.5 ± 5.3	0.98 (0.89 - 1.08)	0.71
Maturational Offset	-2.4 ± 0.5	-2.4 ± 0.7	1.02 (0.43 - 2.43)	0.97
U13-U14 age groups				
Age	13.5 ± 0.8	13.6 ± 0.8	0.80 (0.46 - 1.39)	0.44
Height	159.8 ± 8.9	160.7 ± 9.3	0.99 (0.96 - 1.04	0.64
Weight	47.2 ± 7.6	49.1 ± 8.9	0.97 (0.93 1.02)	0.29
Maturational Offset	-0.8 ± 0.8	-0.4 ± 0.9	0.60 (0.37 - 0.98)	0.04*
U15-U16 age groups				
Age	15.7 ± 0.8	15.7 ± 0.6	1.20 (0.66 - 2.18)	0.55
Height	175.8 ± 8.5	173.0 ± 6.5	1.06 (0.99 - 1.12)	0.06
Weight	64.4 ± 8.7	62.5 ± 7.7	1.03 (0.98 - 1.08)	0.26
Maturational Offset	1.4 ± 0.8	1.4 ± 0.6	1.09 (0.58 - 2.05)	0.80
U18 age group				
Age	17.9 ± 0.6	17.3 ± 0.7	3.55 (1.19 - 10.61)	0.02*
Height	176.9 ± 5.3	179.5 ± 4.4	0.88 (0.76 - 1.02)	0.09
Weight	72.3 ± 6.2	73.1 ± 5.5	0.97 (0.87 - 1.09)	0.68
Maturational Offset	2.9 ± 0.8	3.1 ± 0.6	0.73 (0.29 - 1.85)	0.51

Univariate analysis showed greater knee valgus on the right leg during the TJA was associated with injury (OR, 2.11, CI 1.06-4.18, $P < 0.05$). Heightened levels of asymmetry in the 75%Hop (OR, 0.90, CI 0.84-0.97, $P < 0.001$), SLHD (OR, CI 0.86-0.99, 0.92, p = 0.04) and SLCMJ (OR, 0.85, CI 0.78-0.94, $P < 0.001$) were also associated with a greater risk of injury. Multivariate analysis showed that greater landing force asymmetry during the SLCMJ was the only risk factor significantly associated with an increased risk of lower extremity injury (table 3).

Table 3 Multivariate analyses for all risk factors

Risk Factors	Odds Ratio (95% CI)	*P* Value
U11-U12's		
75%Hop pVGRF Asym	0.93 (0.86 - 1.03)	0.17
TJ Knee Valgus R	1.93 (0.83 - 4.24)	0.10
SLCMJ PVGRF Asym	0.90 (0.82 - 0.99)	0.04*
SLHD Asym	0.92 (0.83 - 1.01)	0.09
U13-U14's		
Maturational Offset	0.58 (0.35 - 0.97)	0.04*
75%Hop (%BW) L	1.55 (0.82 - 2.94)	0.18
75%Hop pVGRF Asym	0.96 (0.91 - 1.01)	0.08
U15-U16's		
Height	1.01 (0.94 - 1.09)	0.76
SLCMJ (%BW) R	0.36 (0.15 - 0.91)	0.03*
SLCMJ pVGRF Asym	0.91 (0.86 - 0.97)	<.001**
U18's		
Age	3.62 (1.05 - 12.49)	0.04*
Height	0.84 (0.68 - 1.033)	0.09
SLHD (% leg length) R	1.54 (0.03 - 84.25)	0.83
75%Hop pVGRF Asym	1.10 (0.99 - 1.21	0.07

U13 and U14 players

Thirty-one players from a sample of one hundred and fourteen sustained an injury across these age groups. Injured participants were further from their age at peak height velocity (PHV) as indicated by a larger maturational offset (table 2). Univariate analysis indicated a trend of increased relative landing forces and heightened asymmetry on the left leg during the 75%Hop; however, no neuromuscular risk factors were significantly associated with injury risk in these

age groups. In the multivariate model, maturational offset was the only risk factor significantly associated with an increased risk of lower extremity injury (table 3).

U15 & U16 players

Thirty-four of the one hundred and eighteen players analyzed in these age groups sustained an injury. No anthropometric variables were significantly associated with a greater injury risk (table 2). Univariate analysis showed that greater relative 75%Hop landing forces on the left leg were significantly associated with a heightened risk of injury (OR, 2.04, CI 1.00-4.17, $P < 0.05$). Lower right leg relative SLCMJ landing forces (OR, 0.34, CI 0.15-0.76, $P < 0.05$) and greater SLCMJ asymmetry (OR, 0.89, CI 0.85-0.95, $P < 0.001$) were also associated with increase injury risk. The multivariate model indicated that magnified SLCMJ landing force asymmetry was associated with greater injury risk as was lower SLCMJ right leg relative body weight landing forces (table 3).

U18 players

Seventeen players sustained an injury from the forty-four players analyzed in this age group. No variables were significantly associated with a greater injury risk in the univariate analysis. In the multivariate model, advancing age chronological age was the only variable associated with injury indicating a three-fold increase in injury risk per *sd* increase (table 3).

DISCUSSION

The current study examined injury risk factors in elite male youth football players using a comprehensive field-based screening test battery. The results showed that in both univariate

and multivariate analyses, combinations of anthropometric and movement based risk factors were associated with lower extremity injury. SLCMJ landing force asymmetry was the most consistently reported risk factor; however, there was variability across the different chronological age groups and a number of screening tests were not related to increased injury risk.

In the current study, SLCMJ peak landing force asymmetry was the most frequently identified risk factor, despite some variation being evident across different chronological age groups. Greater asymmetry was also indicated as a risk factor in the univariate analysis for the SLHD and 75%Hop (U11-12s only), with trends towards significance for 75%Hop asymmetry in the multivariate models of the U13-U14s and U18 players. Asymmetry has been examined previously in male youth football players (2, 8, 42) and is deemed to place additional stress on the weaker leg predisposing it to increased injury risk (19). In adult populations, a discrepancy >15% has been deemed a key predictor of injury (7). Also, subjects with prior history of ACL injury demonstrated greater asymmetry in peak internal knee flexor moments and ground reaction forces during a drop jump landing versus non-injured controls (14). In the current study, asymmetry values > 15% were commonly reported for players who sustained a lower extremity injury. These data indicate that landing force asymmetry is a potential risk factor for injury in this cohort and practitioners should include unilateral assessments that measure landing forces in both vertical and horizontal directions.

An unexpected finding in the current study was that lower right leg relative SLCMJ landing forces were associated with an increased injury risk, in the U15-U16s. Intuitively, higher impact forces on ground contact that exceed the force production capabilities of the involved musculature will increase the loading of soft tissue structures thereby heightening the risk of lower extremity injury (18). A plausible explanation could be that the injured players in this study did not achieve equivalent vertical jump heights in comparison to the non-injured players. Although not a predictor variable in the current study, descriptive analysis showed no

significant differences in vertical jump height between the injured and non-injured players. An alternative hypothesis is that injured players adopted a different kinematic strategy when performing a vertical jump-landing task on their right leg. The majority of players will preferentially utilize their right leg for kicking actions during football match play; thus, greater stability and force absorption would be expected on their contralateral limb. Brophy et al. (5) reported that the majority of anterior cruciate ligament (ACL) injuries in adult football players were to their kicking leg and more recently a combination of knee valgus and ipsilateral trunk motion during a single leg drop vertical landing task was shown as predictor of a non-contact knee injury in female athletes (10). Changes in trunk positioning can alter the resultant ground reaction forces (3) and could in part explain the reduced relative landing scores for the injured players.

Elite youth football players (inclusive of both boys and girls) who demonstrate more landing technique errors during a drop vertical jump tasks have been shown to exhibit a greater risk of ACL injury (33). The results of the current study identified a relationship between dynamic knee valgus during the TJA and heightened injury risk in the U11-12's showing a large odds ratio. The presence of this risk factor could be expected due to the frequency of rapid changes of direction and high force jump-landing activities that occur in the sport (9), in addition to a high occurrence of medial collateral ligament injuries in male youth football (36). Recent data also indicate that elite youth male football players display greater knee valgus angles than older players (41). Cumulatively, this suggests that the assessment of knee valgus during the tuck jump is a worthwhile screen for players in younger chronological age groups.

When examining the anthropometric variables in the current study, chronological age and maturational offset were associated with injury. Advancing chronological age demonstrated a three-fold increase in injury risk for the U18s in both the univariate and multivariate analyses. Injury epidemiological data in elite male youth football players has shown a linear increase in the number of injuries sustained with age (36). A greater frequency

of injury in older players may be due to heightened intensities of play and increased training exposures.

In the present study, no movement-based variables were shown as risk factors for injury in the U13-U14s. Previous literature has identified the period of peak height velocity as a time of heightened injury risk in male youth football players (43, 46) and players in these chronological age groups would most closely align to this stage of maturation. Due to the potential for a period of "adolescent awkwardness" (34) during this time, accurately detecting differences between injured and non-injured players may be more difficult.

While none of the neuromuscular variables were significantly associated with injury risk for the U13s and U14s in this study, a greater maturational offset was strongly associated with increased risk of injury. Recent data indicate heightened injury incidence of overuse injuries in later than earlier maturing players (47), although other studies have reported no difference based on the tempo of maturation (23). The timing of the adolescent growth spurt was not reported in this study; however, practitioners should be cognizant that early and late maturing children will need to be treated differently and this may affect the provision of screening and training strategies for these players (24). Cumulatively, screening to examine injury risk in these age groups may be difficult as indicated by a low prediction accuracy of the multivariate model used to identify injured players in the current study.

It should be acknowledged that the current study was exploratory, whereby, a large number of risk factor variables were included, as opposed to utilizing a hypothesis driven approach; therefore, the findings should be interpreted with caution. Nonetheless, the fact that variation was evident in which risk factors were associated with injury across the different chronological age groups is a salient point for practitioners to consider when planning screening and prevention strategies. It is crucial that screening modalities contain a degree of flexibility to account for changes in injury risk at different stages of development. Although a

core body of tests can be implemented for all age groups for the purposes of longitudinal monitoring, a greater emphasis may be centered on specific risk factors for respective age groups at different stages of growth and maturation. Also, while reductions in neuromuscular control may increase injury risk (17), weak associations between certain test variables included in this study and lower extremity injury suggests that other confounding factors including previous injury and fatigue are also worthy of consideration for future screening test batteries (11, 37, 38).

Practitioners should also be cognisant of other inherent limitations. While previous research has utilised smaller sample sizes to the current study (25, 30, 31, 35), fewer players were included in comparison to other prospective cohort studies conducted in similar athlete populations (33). Nonetheless, due to the paucity of research in elite male youth football players, the current sample was deemed appropriate and can be supported by larger prospective cohort studies in the future. In addition, previous injury which has been reported as a risk factor for future injury occurrence (16) was not included in this study. Due to the frequency with which players move between clubs in academy football, to record this information would have required the use of retrospective analysis. This approach relies on the individual's ability to recall their own injury history and may lead to recall bias which can occur with both long and short term retrospective reporting (12, 20). This factor may be further confounded in youth athletes; thus, previous injury was not included as an adjustment factor. Finally, further examination of risk factors for specific anatomical locations were also not present in this study as too few injuries were recorded across each individual chronological age groups to conduct this type of analysis. Future research should aim to investigate base-line risk factors for key anatomical locations and injury types pertinent to this cohort such as knee and ankle injuries (36) to expand the current body of evidence.

PERSPECTIVES

Greater SLCMJ landing force asymmetry was the test variable most frequently associated with an increased risk of sustaining a non-contact lower extremity injury, with inter-limb differences during the SLHD and 75%Hop also showing some association with injury indicating that asymmetry is a pertinent risk factor for male youth football players. However, variation was evident in the level of association between movement based tests and injury across the different chronological age groups and others showed no association with lower extremity risk which is likely due to the multi-factorial nature of football injuries. Therefore, when working with youth football players, practitioners should ensure that screening approaches contain a degree of flexibility to account for changes in injury risk at different stages of growth and development.

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Conflicts of interest

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

REFERENCES

1. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injury in football. *Am J Sports Med.* 32: 4-16, 2004.
2. Atkins SJ, Hesketh C, Sinclair JK. The presence of bilateral imbalance of the lower limbs in elite youth football players of different ages. *J Strength Cond Res*. 30: 1007-1013, 2016.
3. Blackburn JT, Padua DA. Sagittal-plane trunk position, landing forces, and quadriceps electromyographic activity. *J Athl Train*. 44: 174–179, 2009.
4. Barber S, Frank B, Noyes F, Mangine R, McCloskey J, Hartman W. Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees. *Clin. Orthop. Rel. Res.* 255: 204–214, 1990.
5. Brophy R, Silvers H, Gonzales T, Mandelbaum BR. Gender influences: the role of leg dominance in ACL injury among football players. *BR J Sports Med* 44: 694-697, 2010.
6. Cloke D, Spencer S, Hodson A, Deehan D. The epidemiology of ankle injuries occurring in English football association academies. *Br J Sports Med.* 43: 1119-1125, 2009.
7. Croisier JL, Crielaard JM. Hamstring muscle tears with recurrent complaints: an isokinetic profile. *Isokinetic Exerc Sci.* 8:175-80, 2000.
8. Daneshjoo A, Rahnama N, Mokhtar AH, Yusof A. Bilateral and unilateral asymmetries of isokinetic strength and flexibility in male young professional football players. *J Human Kinetics.* 36: 45-53, 2013.
9. Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman RF. Fate of the ACL injured patient: a prospective outcome study. *Am J Sports Med.* 22: 632-644, 1994.
10. Dingenen B, Malfait B, Nijs S, Peers KHE, Vereecken S, Verschueren SMP, Staes FF. Can two-dimensional video analysis during single-leg drop vertical jumps help identify non-contact knee injury risk? A one-year prospective study. *Clin. Biomech.* 30: 781-787, 2015.
11. Engebretsen L, Bahr R. Intrinsic risk factors for hamstring injuries among male football players: a prospective cohort study. *Am J Sports Med.* 38: 1147-1153, 2010.
12. Gabbe BJ, Finch CF, Bennell KL, and Wajswelner H. How valid is a self-reported 12 month sports injury history? *Br J Sports Med.* 37: 545–547, 2003.
13. Goossens L, Witvrouw E, Vanden Bossche L and De Clercq D. Lower eccentric hamstring strength and single leg hop for distance predict hamstring injury in PETE students. *Eur J Sports Sci.* 15: 436–442, 2015.
14. Goerger BM, Marshall SW, Beutler AI, Blackburn JT, Wickens JH, Padua DA. Asymmetry of lower extremity biomechanics in patients with prior ACL injury: The JUMP-ACL study. Free communications, rapid fire poster presentations: Biomechanical and neuromuscular consequences of ACL injury. 2014.
15. Griffin LY, Angel J, Albohm MJ, Arendt EA, Dick RW, Garrett WE, Garrick J, Hewett TE, Huston L, Ireland ML, Johnson RJ, Kibler BW, Lephart S, Lewis JL, Lindenfield TN, Mandelbaum BR, Marchak P, Teitz CC, Wojtys EM. Non-contact ACL injuries: risk factors and prevention strategies. *J Am Academy Orthop Surg* 8: 141-150, 2000.
16. Hagguland M, Walden M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *Br J Sports Med.* 40: 767-772, 2006.
17. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SJ, van den Bogert AJ, Paterno, MV, Succop P. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *AM J Sports Med.* 33*:* 492-501, 2005.

18. Hewett TE, Ford KR, Hoogenboom BJ, Myer GD. Understanding and preventing ACL injuries: current biomechanical and epidemiological considerations-update. *N Am J Sports Phys Ther*. 5: 234-251, 2010.
19. Hewit J, Cronin J, Hume P. Multidirectional leg asymmetry assessment in sport. *Strength Cond J*. 34: 82-86, 2012.
20. Junge A, Dvorak J. Influence of definition and data collection on the incidence of injuries in football. *Am J Sports Med*. 20: 40-46, 2000.
21. Kucera KL, Marshall SW, Kirkendall DT, Marchak PM, Garrett WE. Injury history as a risk factor for incident in youth football. *Br J Sports Med*. 39: 462-466, 2005.
22. Le Gall, F, Carling C, Reilly T, Vandewalle H, Chruch, J, Rochcongar P. Incidence of injuries in elite French youth football players; a 10-season study. *Am J Sports Med.* 34: 928-938, 2006.
23. Le Gall, F., Carling, C. and Reilly, T. Biological maturity and injury in elite youth football. *Scand J Med Sci Sports*. 17: 564–572, 2007.
24. Lloyd RS, Oliver JL. The youth physical development model: a new approach to long-term athletic development. *Strength Cond J*. 34: 61–72, 2012.
25. Lundgren LE, Tran TT, Nimphius S, Raymond E, Secomb JL, Farley OR, Newton,RU, Steele JR, Sheppard JM. Development and evaluation of a simple, multi-factorial model based on landing performance to indicate injury risk among surfing athletes. *IJSPP*. 10: 1029-1035**,** 2015
26. Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med.* 4:166-170, 1994.
27. Mirwald RL, Baxter-Jones ADG, Bailey DA, Beunen GP. An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc.* 34: 689–694, 2002.
28. Myers RH. Classical and modern regression with applications, 2nd edition. PWS Kent, Boston, MA. Pp. 359, 1990.
29. Myer GD, Stroube BW, DiCesare, Brent JL Ford KR, Heidt RS, Hewett, TE. Augmented feedback supports skill transfer and reduces high-risk injury landing mechanics: a double-blind, randomized controlled laboratory study. *Am J Sports Med.* 41: 669-677, 2013.
30. Newton F, McCall A, Ryan D, Blackburne C, der Funten K, Meyer T, Lewin C, McCunn R. Functional movement screen (FMS™) score does not predict injury in English Premier League youth academy football players. *Science and Medicine in Football*. 2017. doi.org/10.1080/24733938.2017.1283436
31. Nilstad, A, Andersen, TE, Bahr, R, Holme, I and Steffen, K. Risk factors for lower extremity injuries in elite female football players. *Am J Sports Med.* 42: 940-948, 2014.
32. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE, Beutler AI. The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics. *Am J Sports Med.* 37: 1996-2002, 2009.
33. Padua DA, DiStefano LJ, Beutler AI, de La Motte SJ, DiStefano MJ, Marshall SW. The landing errors scoring system as a screening tool for an anterior cruciate ligament injury-prevention program in elite-youth football athletes. *J Athl Train.* 50: 589-595, 2015.
34. Philippaerts RM, Vaeyens R, Janssens M, Van Renterghem B, Matthys D, Craen R, Bourgois J, Vrijens J, Beunen GP, and Malina RM. The relationship between peak height velocity and physical performance in youth football players. *J Sports Sci.* 24: 221–230, 2006.
35. Plisky PJ, Rauh MJ, Kaminski TW, and Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther.* 36: 911–919, 2006.

36. Price RJ, Hawkins RD, Hulse MA, Hodson A. The football association and medical research programme: an audit of injuries in academy youth football. *Br J Sports Med.* 38: 466-471, 2004.
37. Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. Assessment of injury risk factors in male youth football players. *Strength Cond J.* 38: 12-21, 2016a.
38. Read, PJ, Oliver, JL, De Ste Croix, MBA, Myer, GD and Lloyd, RS. Neuromuscular risk factors for knee and ankle ligament injuries in male youth football players. *Sports Med.* 46: 1059–1066, 2016b.
39. Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. Reliability of the tuck jump screening assessment in elite male youth football players. *J Strength Cond Res*. 30: 1510–1516, 2016c.
40. Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. Consistency of field-based measures of neuromuscular control using force plate diagnostics in elite male youth football players. *J Strength Cond Res*. 12: 3304-3311, 2016d.
41. Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. The effects of chronological age and stage of maturation on landing kinematics in elite male youth football players. *J Athl Train.* (in press).
42. Read PJ, Oliver JL, Myer GD, De Ste Croix MBA, Lloyd RS. The effects of maturation on measures of asymmetry during neuromuscular control tests in elite male youth football players. *Ped Ex Sci.* 1-23. doi.org/10.1123/pes.2017-0081.
43. Rumpf M, Cronin J. Injury incidence, body site, and severity in football players aged 6–18 years: implications for injury prevention. *Strength Cond J.* 34: 20-31, 2012.
44. Schmikli SL, de Vries WR, Inklaar H, Backx FJ. Injury prevention target groups in football: injury characteristics and incidence rates in male junior and senior football players. *J Sci Med Sport.* 14: 199-203, 2011.
45. Small K, McNaughton L, Greig M, Lovell R. The effects of multidirectional football-specific fatigue on markers of hamstring injury risk. *J Sci Med Sport.* 13: 120–125, 2010.
46. van der Sluis A, Elferink-Gemser MT, Coelho-e-Sliva MJ, Nijboer JA, Brink MS and Visscher C. Sports injuries aligned to peak height velocity in talented pubertal football players. *Int J Sports Med.* 35: 351–355, 2014.
47. van der Sluis A, Elferink-Gemser MT, Brink MS, Visscher C. Importance of peak height velocity timing in terms of injuries in talented football players. *Int J Sports Med.* 36: 327-332, 2015.
48. Volpi P, Pozzoni R, Galli M. The major traumas in youth football. *Knee Surg Sports Traumatol Arthrosc.* 11: 399-402, 2003.