HHS Public Access

Author manuscript

*Sports Med*. Author manuscript; available in PMC 2017 August 01.

Published in final edited form as:

*Sports Med*. 2016 August ; 46(8): 1059–1066. doi:10.1007/s40279-016-0479-z.

# Neuromuscular Risk Factors for Knee and Ankle Ligament Injuries in Male Youth Soccer Players

**Paul J. Read**[1], **Jon L. Oliver**[2,7], **Mark B. A. De Ste Croix**[3], **Gregory D. Myer**[4,5,6,8], and **Rhodri S. Lloyd**[2,7]

[1]School of Sport, Health and Applied Science, St Mary's University, Waldegrave Road, Twickenham, London TW1 4SX, UK [2]Youth Physical Development Unit, School of Sport, Cardiff Metropolitan University, Cardiff, UK [3]Exercise and Sport Research Centre, School of Sport and Exercise, University of Gloucestershire, Gloucester, UK [4]Division of Sports Medicine, Cincinnati Children's Hospital Medical Center, Cincinnati, OH, USA [5]Department of Pediatrics and Orthopaedic Surgery, College of Medicine, University of Cincinnati, Cincinnati, OH, USA [6]The Micheli Center for Sports Injury Prevention, Boston, MA, USA [7]Sport Performance Research Institute, New Zealand (SPRINZ), AUT University, Auckland, New Zealand [8]Department of Orthopaedics, University of Pennsylvania, Philadelphia, PA, USA

## Abstract

Injuries reported in male youth soccer players most commonly occur in the lower extremities, and include a high proportion of ligament sprains at the ankle and knee with a lower proportion of overuse injuries. There is currently a paucity of available literature that examines age- and sex-specific injury risk factors for such injuries within youth soccer players. Epidemiological data have reported movements that lead to non-contact ligament injury include running, twisting and turning, over-reaching and landing. Altered neuromuscular control during these actions has been suggested as a key mechanism in females and adult populations; however, data available in male soccer players is sparse. The focus of this article is to review the available literature and elucidate prevalent risk factors pertaining to male youth soccer players which may contribute to their relative risk of injury.

## 1 Introduction

The sport of soccer imposes high physiological demands and an inherent risk of injury due to the repeated high intensity movements such as jumping, cutting and contact with opposition players when fatigued [15]. Injuries in male youth soccer players occur mainly in the lower extremities (71–80 %), with a low proportion (5 %) of overuse injuries and a high proportion (20 %) of acute traumatic ligament sprains at the ankle and knee [35, 62, 65]. More specifically, the medial collateral ligament (MCL) and anterior talofibular ligament are the most commonly reported injuries [11, 62].

**Compliance with Ethical Standards**

**Conflicts of interest** Paul Read, Jon Oliver, Mark de Ste Croix, Gregory Myer and Rhodri Lloyd declare that they have no conflicts of interest relevant to the content of this review.

Altered neuromuscular control during dynamic activities (e.g. running, cutting and landing) is indicated as a key mechanism for lower limb ligament injuries [22, 23]. Deficits in neuromuscular control direct excessive stress to the passive ligamentous structures, exceeding their tensile threshold, resulting in mechanical failure [37]. Specific neuromuscular imbalances have been identified for female athletes and adult males including: quadriceps dominance [48], leg dominance [51], ligament dominance [21], trunk dominance [24, 51], neuromuscular activation patterns [33] and dynamic stability [64]. The presence of these deficiencies does not indicate an explicit causative factor for injury per se; however, it should be noted that ligamentous injuries likely occur when active muscular restraints are unable to adequately reduce joint torques during dynamic movements involving deceleration and high forces [9, 61]. In spite of the growing body of evidence in adults and young female athletes, there is a paucity of literature available examining injury risk factors in male youth soccer players. Due to the physical demands of youth soccer, the associated injury risk and the number of children and adolescents who participate in the sport with an age-related increase in incidence [45, 62], there is a clear need for increased research in this cohort to identify age- and sex-specific injury risk factors [2]. This article reviews the available literature and investigates key neuromuscular risk factors that may contribute to their relative risk of injury.

## 2 Quadriceps Dominance

Disproportionate knee moments between recruitment of the quadriceps and hamstrings may be reflective of an imbalance in force absorption [51]. Actions in soccer which require rapid decelerations (such as landing, pivoting and cutting) involve substantial eccentric muscle force contributions from the knee extensors, increasing the risk of non-contact ligamentous injuries [67]. The considerable anterior shear of the tibia relative to the femur is counteracted by the anterior cruciate ligament (ACL), MCL and co-activation of the knee flexors [8, 17]. The functional hamstrings:quadriceps ratio has been shown to increase in post-pubertal children and adolescents as a requirement for co-activation of the hamstrings to reduce anterior tibial translation and high shear forces of the quadriceps during high velocity movements as a form of counterbalance [16]. In male youth soccer players, alterations in the functional hamstring:quadriceps ratio (*H:Q*) may be present due to muscle loading patterns that asymmetrically strengthen the quadriceps during repetitive training and competitions [29]. This alters the reciprocal balance of strength and dynamic stabilization around the knee as indicated by compromised function of the hamstrings during high velocity actions [29].

Confounding factors such as fatigue and previous injury also need to be considered within the remit of injury risk factors as the final stages of a game appear to be a particular time of risk in male youth players [62]. In adults, reports of a more quadriceps-dominant landing strategy and reduced peak muscle activation of the tibialis anterior and hamstrings [57], in addition to changes in the functional *H:Q* ratio [68], have been cited as plausible explanations. Neuromuscular inhibition of the hamstrings may also be present following the occurrence of a hamstring injury [56], and such injuries occur at regular frequencies in elite male youth soccer [35, 62]. The knee flexors are key antagonist muscles, are heavily involved with knee joint stabilization and demonstrate greater deficits in eccentric rather than concentric strength [13, 34]. Cumulatively, it could be conceived that reduced activation of the hamstrings relative to the quadriceps increases injury risk in male youth soccer players. Therefore, practitioners should devise appropriate injury prevention strategies that target deficits in knee flexor strength. Limited data are available in youth populations; however, in collegiate female athletes a 6-week programme of emphasized hamstring resistance training significantly increased the functional *H:Q* ratio to acceptable levels (>1) for the reduction of ACL injuries [28]. Significant improvements in sagittal plane knee kinematics indicative of a reduced quadriceps dominant landing strategy (greater initial contact knee flexion) have also been observed following a short duration (7 weeks) neuromuscular training programme that included both dynamic balance and plyometric exercises [50]. The authors suggested that the prescribed interventions could have increased knee flexor co-contraction; however, muscle activation patterns were not measured. Further research is warranted to examine the effects of such activities on measures of quadriceps dominance in male youth soccer players.

## 3 Leg Dominance

Leg dominance has been defined as an imbalance in strength, coordination and control between the two lower extremities [48]. A discrepancy in excess of 15 % has been deemed a key predictor of injury [13]. Asymmetry places additional stress on the weaker leg, compromising performance and predisposing athletes to various injuries during cutting/landing activities [27]. This risk factor is inherent to soccer, where preferred limb dominance is evident. For example, Zebis et al. [73] identified that during a cutting manoeuvre, all subjects who subsequently experienced an ACL rupture in the following two competitive seasons injured their preferred push-off leg. Additionally, analysis of the distribution of non-contact ACL injuries in male players confirmed 74.1 % injured their dominant (kicking) leg [10]. There is a paucity of data in youth players confirming the presence of asymmetry and associated injury risk. One available study used the star excursion balance test [60]. Logistic regression indicated that high school athletes with an anterior right-left reach difference >4 cm represented a 2.5 times greater risk of lower extremity injury. To the knowledge of the authors, no studies have been conducted with male youth soccer players to examine the relationship between limb dominance and prevalence of injury.

In spite of the lack of available evidence to report the relationship with injury, asymmetry has been reported in male youth soccer players [3, 14]. Daneshjoo et al. [14] measured isokinetic hamstring and quadriceps strength and hip joint flexibility in young male professional soccer players. Of the 36 players tested, all but one reported musculoskeletal imbalances >10 % and heightened levels of dominant leg hip joint range of motion. In addition, Atkins et al. [3] investigated limb asymmetry by examining contralateral differences in peak ground reaction forces during the deep squat exercise in elite male youth soccer players. Based on chronological age, significant differences were identified between limbs ($p \leq 0.05$) in all age groups except for the under thirteens (U13s) and under seventeens (U17s) (the youngest and oldest groups, respectively), indicating that asymmetry increases during the period of peak height velocity (PHV) and the early stages of adolescence. This time-point corresponds with a stage of adolescent awkwardness, in which decrements in motor skill performance are often evident resulting from rapid gains in limb length [39, 59].

Further, elite male youth soccer players experience more traumatic injuries in the year of PHV [70], and total injury incidence is highest in this period [62, 65]. An awareness of leg dominance and the development of appropriate screening protocols will aid practitioners to identify youth players who may be at a greater risk of injury. Utilizing single limb tasks is preferred to bilateral variations due to their enhanced ability and sensitivity for determining deficits in neuromuscular control [51]. Furthermore, assessments of leg power across multiple directions (vertical, horizontal and lateral) have reported insignificant relationships between tests in the various movement planes [27, 41, 44]. Testing athletes across different directions may measure relatively independent leg-power qualities, thus utilizing a range of assessments targeting multi-planar actions is recommended. When interpreting athlete test scores, practitioners should also be cognizant that accurately determining an asymmetry threshold to predict injury is challenging. Adult data indicate a 15 % difference between limbs increases injury risk; however, currently no research is available to examine the relationship between asymmetry and injury risk in male youth soccer players, and this requires further investigation.

## 4 Ligament Dominance

Dynamic valgus alignment has been defined as a medial or valgus collapse of the knee during tasks which involve hip and knee flexion [23, 48]. Displacement primarily occurs in the frontal plane from a combination of hip internal rotation, knee valgus and tibial external rotation [33]. This is coupled with decreased knee and hip flexion angles and pronation at the subtalar joint [10]. Such knee positions indicative of reduced frontal plane control on ground contact have been reported in male subjects who subsequently experienced an ACL injury [58]. Due to the increased load on the MCL and ACL in this position, greater valgus angles have been indicated as a predisposing injury risk factor for athletes [23]. In male youth soccer, incidence reports have confirmed that 17.1 % of all injuries occur at the knee [35, 47], and the MCL accounts for between 77 and 83 % of all knee ligament injuries [47, 62]. The knee is also the most frequent site of major injuries (classified as >4 weeks absence from match play) in this population [71], most commonly ACL lesions (all of which required surgery), followed by meniscal and MCL sprains.

Knee valgus has been a commonly associated risk factor for non-contact ACL injury in female athletes [23]. During the prepubescent period, similar valgus alignment has been reported between boys and girls [4, 19, 63]. In a large cohort study, Barber-Westin et al. [5] identified that during a drop jump test, although boys (aged between 9 and 17 years) had greater mean ankle and knee separation distances than aged-matched girls on take-off, a large proportion of the boys displayed distinct lower limb valgus alignment upon landing. No significant sex differences for mean total medial knee displacement were present and normalized medial knee displacement difference between boys and girls aged 15 years was minimal. Therefore, this risk factor may be present in both youth males and females. However, caution should be applied to the findings of Barber-Westin et al. [5], as sizeable variability was present in the data; the study only used a single-plane camera setup which may have limited the accuracy of identifying potential differences. These findings also conflict with previous investigations that have reported that after the onset of maturation, girls display greater medial knee displacement than boys [22].

During the prepubescent period, ACL injury occurrence is less frequent [69]; however, the risk of ligament sprain increases as youth approach adolescence [1]. Smaller stature, lower body mass and relatively slower velocities of play involved in children's sporting activities may help reduce the risk of injury in pre-pubertal athletes [5]. Cumulatively, the available data show that younger male players will display greater levels of knee valgus than older youths; however, these findings are not consistent across the all investigations [55]. A lack of evidence currently exists to describe knee angles during landing and cutting-based tasks for male youth soccer players at different stages of growth and maturation and their association with injury risk. This requires further investigation to validate its presence as a relevant risk factor for knee injury in this cohort. However, due to the potential for increased injury risk, young male soccer players, and specifically those who demonstrate valgus alignment upon landing, should be targeted to undertake a progressive and periodized integrative neuromuscular training (INT) programme comprised of general and specific activities including strength-building, plyometrics, balance and agility [28]. This should be completed in addition to their regular soccer practice due to the beneficial effects of INT on lower extremity kinematics [50, 52, 53].

## 5 Neuromuscular Feed-Forward Strategies

During actions such as landing from a jump or side cutting in competitive match play, the time available for decision making and postural repositioning is limited. These reactive tasks provide insufficient time to make the necessary postural adjustments, resulting in compromised leg positioning and significantly greater loads on the knee joint [7]. Moreover, Krosshaug et al. [33] using in-vivo video analysis reported that the timing of non-contact ACL injury ranged between 17 and 50 ms following initial ground contact. This short timeframe does not provide a suitable period to utilize reflexive neuromuscular feedback mechanisms, but rather relies on feed-forward muscle activation. This serves to maintain joint integrity by providing early recruitment of the involved musculature prior to loading to better enable force absorption and, in doing so, reducing joint torques and ligamentous loadings [6, 7, 23]. Therefore, altered or imbalanced sequences of neuromuscular firing during dynamic actions occurring in soccer such as landing or cutting may increase the risk of injury.

There is a paucity of research that has examined the relationship between muscle pre-activation and injury risk in paediatric populations. Available literature has compared muscle pre-activation in pre-pubescent boys (aged 9–11 years) and post-pubescent males (aged 19–29 years) during a vertical jumping task [12]. Post-pubescent youth displayed greater levels of hamstring activity and co-contraction ratio prior to landing. Conversely, greater hamstring activity post-landing and during initial contact to maximum knee flexion was present in pre-pubertal subjects, indicating greater co-contraction ratios post-landing than older subjects. Intuitively, this suggests that a more efficient neuromuscular feed-forward strategy is developed prior to landing as males mature to control ground reaction forces and regulate anterior displacement of the knee. Confirming this, research shows that preparatory co-contraction ratios were two times higher in adults compared to children in landing from a vertical jump task [66]. Data also show that as children mature they become more reliant on supra-spinal feed-forward input and short latency stretch reflexes [38], suggesting that pre-activation strategies are a learnt skill that develop with maturation. During a period of adolescent awkwardness, disrupted sequences of neuromuscular feed-forward muscle recruitment may increase injury risk; re-establishing the correct performance of fundamental motor skills and landing mechanics is thus an important consideration for practitioners responsible for youth-based exercise prescription. Furthermore, practitioners should consider the inclusion of plyometric exercises to reduce the risk of injury. Data are available in young female athletes that show 6 weeks of plyometric training increased preparatory muscle activation of the adductors and abductor-adductor coactivation ratio, which was suggestive of a training-induced pre-active motor strategy [20]. Thus, while this study utilized female subjects, it could be inferred that such activities would also be beneficial for male youth soccer players; however, this requires further investigation.

## 6 Dynamic Balance

Effective performance of both static and dynamic stability tasks requires the integration of visual, vestibular and proprioceptive inputs which provide an efferent response to control the body's centre of mass within its base of support [20]. Deficits in postural control and reflex stabilization have been reported in the assessment of subjects with functional ankle instability via the calculation of time to stabilization [64]. A delay in neural feedback responses, which contribute to lower limb stability, may increase injury risk highlighted by the timing of ACL injuries 17–50 ms after initial ground contact [33]. In male soccer players, the physiological training effects of a warm-up injury prevention programme have been reported and time to stabilization in the training group was 90 ms faster than the soccer training-only matched controls [31]. Therefore, it can be implied that shorter muscle feedback responses will enhance neuromuscular control via active restraint, thus lowering injury risk.

Available data to confirm relationships between impaired dynamic stability and injury risk in youth populations is sparse. Previous literature has suggested that maturation of the neurological, visual, vestibular and proprioceptive systems may lead to enhanced performance during single leg balancing tasks [46]. Younger subjects demonstrate greater postural sway during single leg balance maneuvers which may compromise stability [46]. In male high school basketball players, higher postural sway during unilateral balancing was also associated with increased risk of ankle sprain [42]. Subjects who demonstrated greater sway experienced nearly seven times as many ankle sprains as those with good balance. In male youth soccer, ankle injuries account for 19 % of total injury incidence [11] and the most common diagnosis is anterior talofibular ligament sprain [62]. Improving dynamic balance has significantly reduced the risk of ankle sprains in high school soccer and basketball players who performed a series of single leg balance and squat exercises in both stable and unstable conditions (risk ratio 0.56; 95 % confidence interval (CI) 0.33–0.95; $P = 0.033$) [43]. Moreover, youth male soccer players undertaking a proprioception training intervention enhanced postural stability indices in both anterior-posterior and medial-lateral directions on the star excursion balance test [40]. Additionally, a significant reduction in the number of knee and ankle sprains was reported across the course of a soccer season in these players in comparison to those who only completed their normal soccer training [40]. Enhanced trunk stabilization may also improve dynamic stability and balance due to improved trunk motion control [26]. This has been confirmed in male youth soccer players, whereby an intervention consisting of trunk stabilization exercises including quadruped contralateral raises, front planks, back and side bridges enhanced performance during specified reach directions of the star excursion balanced test and single leg static balance tasks [30]. Cumulatively, the available literature suggests that deficiencies in dynamic stability may increase the risk of lower limb injuries in male youth soccer players. Targeting these deficits using appropriately prescribed balance and trunk stabilization exercises may subsequently reduce this risk.

## 7 Trunk Dominance

Trunk dominance has been defined as an imbalance between the inertial demands of the trunk and the ability of the 'core' to resist perturbations to the centre of mass [24, 51]. This inability to dissipate force effectively results in excessive trunk motion primarily in the frontal plane and increased ground reaction forces and knee joint torques [25]. When distal segments are fixed during closed chain sporting actions, motion at more proximal segments will influence the kinetics and kinematics of other segments in the chain [36]. A key action of the abdominal musculature is to provide adequate control of the pelvis due to increases in femoral internal rotation and adduction which may be coupled with increased anterior pelvic tilt [32]. Active proprioceptive repositioning of the trunk has also predicted knee injury status with 90 % sensitivity and 56 % specificity in female athletes [72]. Thus, reduced pre-activation of the trunk may result in a loss of control of the body's centre of mass and can be considered essential for controlling excessive spinal motions which may contribute to altered biomechanics of the lower limbs during dynamic movements in soccer.

There is currently a paucity of literature pertaining to measures of core stability, trunk dominance and injury incidence in youth male soccer players. While the aforementioned assessments [72] have demonstrated favourable results, it should be considered that such measures were derived during artificial conditions and postures in which the pelvis is immobilized, limiting contributions from more distal musculature. Ecological validity may be questioned and the highly specialized and costly equipment will likely limit application to larger scale youth athlete screening programmes. Alternative field-based trunk muscle endurance assessments also contain ecological validity concerns due to their prolonged isometric actions and non-functionality. This is confounded by data reporting weak-moderate relationships (intra-class correlation coefficient range = 0.37–0.62) between performance on isometric trunk endurance tests and a range of athletic measures [54]. Moreover, Leetun et al. [36] analyzed isometric trunk endurance tests and additional measures of hip abduction and external rotation strength, identifying that hip external rotation strength was the only useful predictor of injury status (odds ratio 0.86; 95 % CI 0.77–0.097). Therefore, further investigation is required to elucidate if trunk dysfunction is a prevalent risk factor in youth male soccer players. In addition, appropriate trunk dominant neuromuscular control tests are needed to accurately measure potential deficits that may predispose athletes to a greater risk of injury.

## 8 Injury Risk Factor Hierarchical Model

Following the identification of prevalent injury risk factors, the authors propose a systematic model to screen male youth players and subsequently develop individualized programmes to reduce their relative risk of knee and ankle injuries (Fig. 1). Each risk factor is linked to a neuromuscular screening assessment and target exercises are then selected to improve relevant neuromuscular control deficits. It is beyond the scope of this review to discuss each assessment listed here; however, practitioners are encouraged to examine comprehensive reviews that discuss their application [48, 51] and to utilize assessments that: (1) focus on mechanisms and associated risk factors of injury, (2) are able to detect functional deficits assisting in the early identification of players at high risk, and (3) demonstrate suitable validity and reliability. Also, practitioners may wish to assess their players’ movement abilities under conditions of fatigue to determine changes in neuromuscular control. In male youth soccer, injuries occur more frequently towards the end of the first and second halves, respectively [62]. Solely screening players in a non-fatigued state may not accurately identify those individuals whose movement mechanics deteriorate towards the end of a match, affecting their relative risk of injury.

The final step requires the selection of appropriate exercises that are associated with each test. It is proposed that following an appropriate training intervention, neuromuscular deficits can be reduced, lowering injury risk. In selecting exercises to reduce injury risk, practitioners are advised to consider INT [52]. The integration of such activities that develop fundamental movement skills should be initiated during pre-adolescence and maintained through adolescence to enhance skill-related fitness and reduce the risk of sports-related injury [18, 49, 53]. Periodized INT programmes included during the pre- and off-season periods are also critical, especially for youth soccer players who engage in specialized sports practice where exposure to a wide range of developmental motor skill activities is limited [52].

## 9 Conclusions

The occurrence of lower limb injuries in male youth soccer players is highly prevalent, with risk increasing as players grow and mature. This review has identified neuromuscular imbalances for common injuries in male youth soccer providing an overview of the available paediatric literature. Existing research suggests that heightening neuromuscular control in the aforementioned areas may reduce the risk of injury in male youth soccer players; however, practitioners should be cognizant that available data in this cohort are sparse. A hierarchical injury risk factor model has also been proposed to provide practitioners with a systematic model to screen youth players and determine their level of risk. Hypothetically, this information can then be used to develop individualized programmes that target deficits in neuromuscular control.

## Acknowledgments

**Funding** No sources of funding were used to assist in the preparation of this article. One author (Gregory Myer) would like to acknowledge funding support from National Institutes of Health Grants R21-AR065068.

## References


1. Adrim TA, Cheng TL. Overview of injuries in the young athlete. Sports Med. 2003; 33:75–81. [PubMed: 12477379]
2. Alentorn-Geli E, Mendiguchıa J, Samuelsson K, et al. Prevention of anterior cruciate ligament injuries in sports—part I: systematic review of risk factors in male athletes. Knee Surg Sports Traumatol Arthrosc. 2014; 22:3–15. [PubMed: 24385003]
3. Atkins SJ, Hesketh C, Sinclair JK. The presence of bilateral imbalance of the lower limbs in elite youth soccer players of different ages. J Strength Cond Res. 2015 (in press).
4. Barber-Westin SD, Galloway M, Noyes FR, et al. Assessment of lower limb neuromuscular control in prepubescent athletes. Am J Sports Med. 2005; 33:1853–60. [PubMed: 16157852]
5. Barber-Westin D, Noyes FR, Galloway M. Jump-land characteristics and muscle strength development in young athletes. A gender comparison of 1140 athletes 9 to 17 years. Am J Sports Med. 2006; 34:375–84. [PubMed: 16282578]
6. Beard DJ, Kyberd PJ, Fergusson CM, et al. Proprioception after rupture of the anterior cruciate ligament. An objective indication of the need for surgery? J Bone Joint Surg. 1993; 75:311–5. [PubMed: 8423193]
7. Besier TF, Lloyd DG, Ackland TR, et al. Anticipatory effects on knee joint loading during running and cutting maneuvers. Med Sci Sport Exerc. 2001; 33:1176–81.
8. Beynnon B, Howe JG, Pope MH, et al. The measurement of ACL strain in-vitro. Int Orthop. 1992; 16:1–12. [PubMed: 1572761]
9. Beynnon BD, Fleming BC. Anterior cruciate ligament strain in-vivo: a review of previous work. J Biomech. 1998; 31:519–25. [PubMed: 9755036]
10. Brophy R, Silvers H, Gonzales T, et al. Gender influences: the role of leg dominance in ACL injury among soccer players. Br J Sports Med. 2010; 44:694–7. [PubMed: 20542974]
11. Cloke D, Spencer S, Hodson A, et al. The epidemiology of ankle injuries occurring in English Football Association academies. Br J Sports Med. 2009; 43:1119–25. [PubMed: 19106152]
12. Croce RV, Russell PJ, Swartz EE, et al. Knee muscular response strategies differ by developmental level but not gender during jump landing. Electromyogr Clin Neurophysiol. 2004; 44:339–48. [PubMed: 15473345]
13. Crosier JL, Crelaard JM. Hamstring muscle tear with recurrent complaints: an isokinetic profile. Isokinet Exerc Sci. 2000; 8:175–80.
14. Daneshjoo A, Rahnama N, Mokhtar AH, et al. Bilateral and unilateral asymmetries of isokinetic strength and flexibility in male young professional soccer players. J Hum Kinet. 2013; 36:45–53. [PubMed: 23717354]
15. Daniel DM, Stone ML, Dobson BE, et al. Fate of the ACL-injured patient: a prospective outcome study. Am J Sports Med. 1994; 22:632–44. [PubMed: 7810787]
16. De Ste Croix MBA. Advances in paediatric strength assessment: changing our perspective on strength development. J Sports Sci Med. 2007; 6:292–304. [PubMed: 24149415]
17. Draganich LF, Vahey JW. An in-vitro study of ACL strain induced by quadriceps and hamstring forces. J Orthop Res. 1990; 8:57–63. [PubMed: 2293634]
18. Faigenbaum AD, Farrell A, Fabiano M, et al. Effects of integrative neuromuscular training on fitness performance in children. Pediatr Exerc Sci. 2011; 23:573–84. [PubMed: 22109781]
19. Ford KR, Shapiro R, Myer GD, et al. Longitudinal sex differences during landing in knee abduction in young athletes. Med Sci Sports Exerc. 2010; 42:1923–31. [PubMed: 20305577]
20. Guskiewicz KM, Perrin DH, Gansneder B. Effect of mild head injury on postural stability in athletes. J Athl Train. 1996; 31:300–6. [PubMed: 16558414]
21. Hewett TE, Paterno MV, Myer GD. Strategies for enhancing proprioception and neuromuscular control of the knee. Clin Orthop. 2002; 402:76–94.
22. Hewett TE, Myer GD, Ford KR. Decrease in neuromuscular control about the knee with maturation in female athletes. J Bone Joint Surg Am. 2004; 86:1601–8. [PubMed: 15292405]

23. Hewett TE, Myer GD, Ford KR, et al. 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. 2005; 33:492–501. [PubMed: 15722287]
24. Hewett TE, Ford KR, Myer GD, et al. Effect of puberty and gender on landing force and jump height. Med Sci Sports Exerc. 2005; 37:S66.
25. Hewett T, Johnson D. ACL prevention programs: fact or fiction? Orthopedics. 2010; 33:36–9. [PubMed: 20052952]
26. Hewett TE, Myer GD. The mechanistic connection between the trunk, knee, and anterior cruciate ligament injury. Exerc Sport Sci Rev. 2011; 39:161–6. [PubMed: 21799427]
27. Hewit J, Cronin J, Hume P. Multidirectional leg asymmetry assessment in sport. Strength Cond J. 2012; 34:82–6.
28. Holcomb WR, Rublet MD, Lee HJ, et al. Effect of hamstring-emphasized resistance training on hamstring: quadriceps strength ratios. J Strength Cond Res. 2007; 21:41–7. [PubMed: 17313266]
29. Iga J, George K, Lees A, et al. Cross-sectional investigation of indices of isokinetic leg strength in youth soccer players and untrained individuals. Scand J Med Sci Sports. 2009; 19:714–9. [PubMed: 18627555]
30. Imai A, Kaneoka K, Okubo Y, et al. Effects of two types of trunk exercises on balance and athletic performance in youth soccer players. Int J Sports Phys Ther. 2014; 9:47–57. [PubMed: 24567855]
31. Imprezzilini F, Bizzini M, Dvorak J, et al. Physiological and performance responses to the FIFA 11+ (part 2): a randomised control trial on the training effects. J Sport Sci. 2013; 31:1491–502.
32. Ireland ML. The female ACL: why is it more prone to injury? Orthop Clin North Am. 2002; 33:637–51. [PubMed: 12528906]
33. Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. Am J Sports Med. 2007; 35:359–67. [PubMed: 17092928]
34. Lee TQ, Anzel SH, Bennett KA, et al. The influence of fixed rotational deformities of the femur on the patellofemoral contact pressures in human cadaver knees. Clin Orthop. 1994; 302:69–74.
35. Le Gall F, Carling C, Reilly T, et al. Incidence of injuries in elite French youth soccer players; a 10-season study. Am J Sports Med. 2006; 34:928–38. [PubMed: 16436535]
36. Leetun D, Ireland M, Wilson J, et al. Core stability measures as risk factors for lower extremity injury in athletes. Med Sci Sport Exerc. 2004; 36:926–34.
37. Li G, Rudy TW, Allen C, et al. Effect of combined axial compressive and anterior tibial loads on in situ forces in the anterior cruciate ligament: a porcine study. J Orthop Res. 1998; 16:122–7. [PubMed: 9565084]
38. Lloyd RS, Oliver JL, Hughes MG, et al. Age-related differences in the neural regulation of stretch–shortening cycle activities in male youths during maximal and sub-maximal hopping. J Electromyogr Kinesiol. 2012; 22:37–43. [PubMed: 22000942]
39. Lloyd RS, Oliver JL, Faigenbaum AD, et al. Chronological age vs. biological maturation: implications for exercise programming in youth. J Strength Cond Res. 2014; 28:1454–64. [PubMed: 24476778]
40. Malliou P, Gioftsidou A, Pafis G, et al. Proprioceptive training (balance exercises) reduces lower extremity injuries in young soccer players. J Back Musculoskelet Rehabil. 2004; 17:101–4.
41. Maulder P, Cronin J. Horizontal and vertical jump assessment: reliability, asymmetry, discriminative and predictive ability. Phys Ther Sport. 2005; 6:74–82.
42. McGuine TA, Greene JJ, Best T, et al. Balance as a predictor of ankle injuries in high school basketball players. Clin J Sports Med. 2000; 10:239–44.
43. McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. Am J Sports Med. 2006; 34:1103–11. [PubMed: 16476915]
44. Meylan C, McMaster T, Cronin J, et al. Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. J Strength Cond Res. 2009; 23:1140–7. [PubMed: 19528866]
45. Michaud PA, Renaud A, Narring F. Sports activities related to injuries? A survey among 9–19 year olds in Switzerland. Inj Prev. 2001; 7:41–5. [PubMed: 11289534]

46. Mickle KJ, Munro BJ, Steele JR. Gender and age affect balance performance in primary school-aged children. J Sci Med Sport. 2011; 14:243–8. [PubMed: 21276751]
47. Moore O, Cloke DJ, Avery PJ, et al. English Premiership Academy knee injuries: lessons from a 5 year study. J Sports Sci. 2011; 29:1535–44. [PubMed: 21988085]
48. Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for ACL injury prevention among female athletes. J Athl Train. 2004; 39:352–64. [PubMed: 15592608]
49. Myer GD, Ford KR, Palumbo JP, et al. Neuromuscular training improves performance and lower extremity biomechanics in female athletes. J Strength Cond Res. 2005; 19:51–60. [PubMed: 15705045]
50. Myer GD, Ford KR, McLean SG, et al. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. Am J Sports Med. 2006; 34:445–55. [PubMed: 16282579]
51. Myer GD, Brent JL, Ford KR, et al. Real-time assessment and neuromuscular training feedback techniques to prevent ACL injury in female athletes. Strength Cond J. 2011; 33:21–35. [PubMed: 21643474]
52. Myer GD, Faigenbaum AD, Chu DA, et al. Integrative training for children and adolescents: techniques and practices for reducing sports-related injuries and enhancing athletic performance. Phys Sportsmed. 2011; 39:74–84. [PubMed: 21378489]
53. Myer GD, Faigenbaum AD, Ford KR, et al. When to initiate integrative neuromuscular training to reduce sports-related injuries in youth? Curr Sports Med Rep. 2011; 10:155–66. [PubMed: 21623307]
54. Nesser TW, Huxel KC, Tincher JL, et al. The relationship between core stability and performance in Division I football players. J Strength Cond Res. 2008; 22:1750–4. [PubMed: 18978631]
55. Noyes FR, Barber-Westin SD, Fleckenstein C, et al. The drop-jump screening test: difference in lower limb control by gender and effect of neuromuscular training in female athletes. Am J Sports Med. 2005; 33:197–207. [PubMed: 15701605]
56. Opar D, Timmins R, Dear N, et al. The role of neuromuscular inhibition in hamstring strain injury recurrence. J Electromyogr Kinesiol. 2013; 23:523–30. [PubMed: 23402871]
57. Padua D, Arnold B, Perrin D, et al. Fatigue, vertical leg stiffness and stiffness control strategies in males and females. J Athl Train. 2006; 41:294–304. [PubMed: 17043698]
58. Padua DA, Marshall SW, Boling MC, et al. The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics. Am J Sports Med. 2009; 37:1996–2002. [PubMed: 19726623]
59. Philippaerts RM, Vaeyens R, Janssens M, et al. The relationship between peak height velocity and physical performance in youth soccer players. J Sports Sci. 2006; 24:221–30. [PubMed: 16368632]
60. Plisky PJ, Rauh MJ, Kaminski TW, et al. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. J Orthop Sports Phys Ther. 2006; 36:911–9. [PubMed: 17193868]
61. Powell JW, Barber-Foss KD. Sex related injury patterns among selected high school sports. Am J Sports Med. 2000; 28:385–91. [PubMed: 10843133]
62. Price RJ, Hawkins RD, Hulse MA, et al. The Football Association and medical research programme: an audit of injuries in academy youth football. Br J Sports Med. 2004; 38:466–71. [PubMed: 15273188]
63. Quatman CE, Ford KR, Myer GD, et al. Maturation leads to gender differences in landing force and vertical jump performance: a longitudinal study. Am J Sports Med. 2005; 34:1–8.
64. Ross S, Guskiewicz K. Assessment tools for identifying functional limitations associated with functional ankle instability. J Athl Train. 2008; 43:44–50. [PubMed: 18335012]
65. Rumpf M, Cronin J. Injury incidence, body site, and severity in soccer players aged 6–18 years: implications for injury prevention. Strength Cond J. 2012; 34:20–31.
66. Russell PJ, Croce RV, Swart EE, et al. Knee muscle activation during landings: developmental and gender comparisons. Med Sci Sports Exerc. 2007; 39:159–69. [PubMed: 17218898]

67. Simonsen EB, Magnusson SP, Bencke J, et al. Can the hamstring muscles protect the anterior cruciate ligament during a side-cutting maneuver? Scand J Med Sci Sports. 2000; 10:78–84. [PubMed: 10755277]

68. Small K, McNaughton L, Greig M, et al. The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. J Sci Med Sport. 2010; 13:120–6. [PubMed: 18976956]

69. Tursz A, Crost M. Sports related injuries in children: a study of their characteristics, frequency and severity with comparison to other accidental injuries. Am J Sports Med. 1986; 14:294–9. [PubMed: 3728781]

70. Van der Sluis A, Elferink-Gemser MT, Coelho-e-Sliva MJ, et al. Sports injuries aligned to peak height velocity in talented pubertal soccer players. Int J Sports Med. 2014; 35:351–5. [PubMed: 24022568]

71. Volpi P, Pozzoni R, Galli M. The major traumas in youth football. Knee Surg Sports Traumatol Arthrosc. 2003; 11:399–402. [PubMed: 14618321]

72. Zazulak BT, Hewett TE, Reeves NB, et al. The effects of core proprioception on knee injury: a prospective biomechanical epidemiological study. Am J Sports Med. 2007; 35:368–73. [PubMed: 17267766]

73. Zebis MK, Andersen LL, Bencke J, et al. Identification of athletes at future risk of ACL ruptures by neuromuscular screening. Am J Sports Med. 2009; 37:1967–73. [PubMed: 19574475]

### Key Points

- The occurrence of lower limb injuries, specifically occurring at the knee and ankle, in male youth soccer players is highly prevalent, with altered neuromuscular control during dynamic activities indicated as a potential injury mechanism.
- Specific neuromuscular imbalances have been identified as risk factors for ligamentous injuries including quadriceps dominance, leg dominance, ligament dominance, trunk dominance, neuromuscular feed-forward muscle activation patterns and dynamic stability.
- Existing research suggests that heightening neuromuscular control in the aforementioned areas may reduce the risk of injury in male youth soccer players; however, available data in this cohort are sparse.

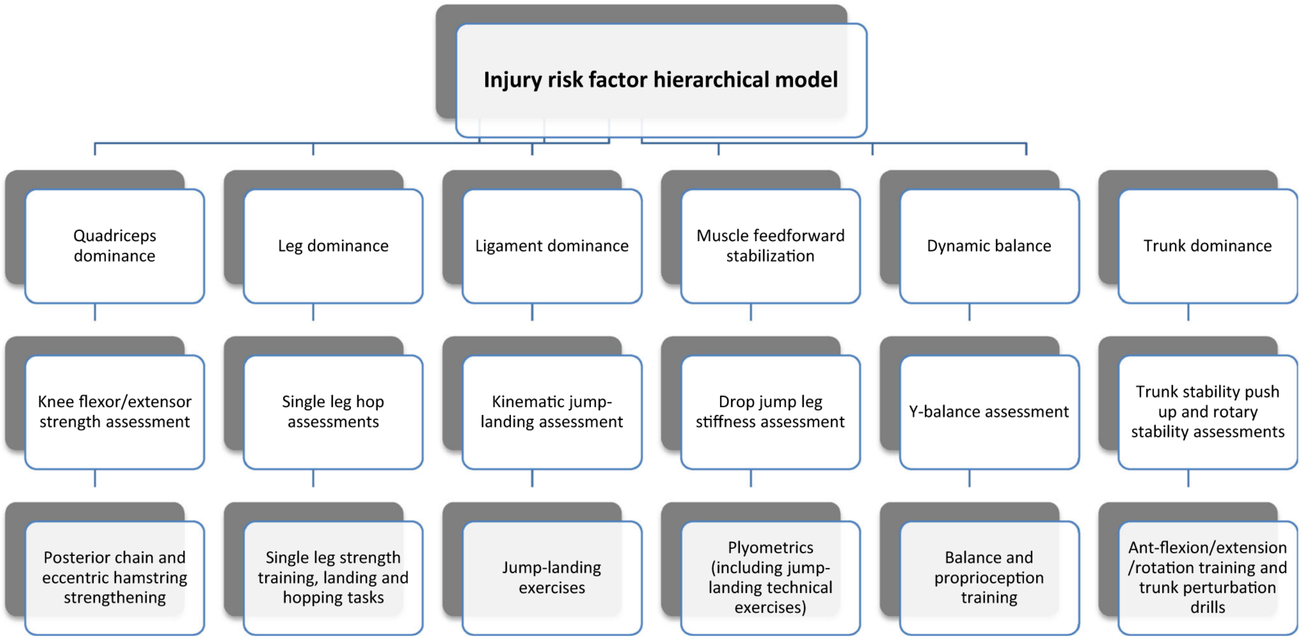


**Fig. 1.**

Knee and ankle ligament injury neuromuscular risk factor hierarchical model. The top tier of the model includes identification of the associated neuromuscular risk factors for knee and ankle ligament injuries. Practitioners are then required to select appropriate assessments that are able to detect functional deficits assisting in the early identification of players at high risk (tier 2 of the model). The final step involves the selection of appropriate exercises that target each of the respective neuromuscular risk factors. It is proposed that following an appropriate training intervention, test performance will improve and subsequent neuromuscular deficits can be reduced, lowering injury risk