# A REVIEW OF FIELD-BASED ASSESSMENTS OF NEUROMUSCULAR CONTROL AND THEIR UTILITY IN MALE YOUTH SOCCER PLAYERS

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## Abstract

Lower extremity injuries in male youth soccer are common and equate to a substantial time-loss from training and competitions during the course of a season. Extended periods of absence will impact player involvement in skill and physical development activities, as well as participation in competitive match play. Neuromuscular risk factors for lower extremity injury in male youth soccer players can be categorized into quadriceps dominance; leg dominance; ligament dominance; trunk dominance and reduced dynamic stability. Valid screening methods to identify risk factors that are practically viable are needed for youth athletes who may be at a greater risk of injury in soccer. While field-based tests of neuromuscular control provide a reliable option for the assessment of injury risk in adults and females, less data are available in male youth soccer players and further research is required to examine their ability to predict injury risk. This article provides a review of the current literature pertaining to field-based screening tests and critically appraises their suitability for use with male youth soccer players. Currently the only method that has been validated in male youth soccer players is the landing error scoring system. Asymmetrical anterior reach measured during the Y-Balance test may also be considered due to its strong predictive ability in male youth basketball players; however, further research is required to fully support its use with soccer players.

**Key words**

Screening, injury risk, applied, adolescent

## 1.0 Introduction

Injury incidence in male youth soccer ranges from 2.0 – 26.6 injuries per 1000 hours of exposure with the majority of these injuries occurring in the lower extremity (13, 44, 50). Player incidence rate has also been reported as 0.40 per player, per season, and a mean absence of 21.9 days per injury (80). These substantial periods of time-loss have a distinct impact on player involvement in skill and physical development activities as well as participation in competition. Neuromuscular risk factors for lower extremity injury in male youth soccer players have previously been suggested (62, 82, 83, 84). These include quadriceps dominance, leg dominance (asymmetry), frontal plane knee control (knee valgus), trunk dominance and reduced dynamic stability (83, 84). Appropriate screening methods to assess deficits in neuromuscular control are important for practitioners to identify youth athletes who may be at a greater risk of injury (83, 84, 102). The practical application of such measurements also has to be considered due to the cost and time implications of screening a large number of athletes; thus, in the context of a soccer academy, field-based assessments are likely more appropriate. The purpose of this review is to critically appraise and describe a range of field-based screening tests, and discuss their suitability for use with male youth soccer players. Available tests from the existing literature have been included for each risk factor so that practitioners can examine their validity and reliability. This is supported by a test battery that may be considered for use with this cohort.

## 2.0 Assessment of quadriceps dominance

*Handheld dynamometry*

Similar to the principles of manual muscle testing, handheld dynamometry utilises a portable measurement device positioned between the hand of the test administrator and the part of body part being tested on the athlete. Handheld dynamometry of the lower extremity is used to objectively quantify the greatest force applied to the leg that an individual can resist during an isometric muscle action (98). This method can be easily administered to assess strength imbalances of the knee flexors and extensors. Test-retest reliability for the handheld dynamometer has been shown to be highly reliable (ICC = 0.95) (10) and a systematic review to examine the relationships between hand-held and isokinetic dynamometry concluded that moderate-strong agreement is consistently shown between these two methods (range, r = 0.43 – 0.86) (98). The large range of correlations reported could be attributed to a lack of standardized test procedures, including patient / practioner positioning, the level of training provided for the test administrator and how the force was applied (patient versus practioner initiated) (98).

Despite the apparent ease of implementation for this technique, distinct limitations are present, including no control or variation in movement speed which limits the interpretation of muscle torque relationships during high speed manoeuvres and performance may be affected by previous injury (88). Practitioners must also be highly skilled and display sufficient strength to resist the individual. This may be suitable for younger players, but with advanced maturity and strength, older players may be able to overcome the manual resistance of the tester (10). A method to overcome this limitation is to stabilize the dynamometer against an immovable object or strap down the participant (49). This method has shown adequate sensitive for identifying adult athletes at a greater risk of back and lower extremity, where lower hip external strength deficits were present (49). However, there is a paucity of literature in pediatric populations using this technique, with a majority of studies using handheld dynamometry focusing on subjects with neuromuscular disorders (11, 21, 101). To the knowledge of the authors no research is available to examine strength deficits measured using hand held dynamometry in youth athletes or male youth soccer players. Further research is required prior to recommending this testing modality for use with this cohort.

*Force plate hamstring strength tests*

A simple and practically viable technique that may be used to assess isometric hamstring strength has been proposed recently in male professional soccer players (53). In this test, the knee is flexed at either 90° or 30° to preferentially recruit the semimembranosus, semitendinosus or biceps femoris respectively (68) and the peak force exerted is measured in a supine position with the heel of the testing leg placed on a raised force platform. Until recently, the use of force plates may not have been practically viable for practitioners working in the field; however, more cost effective equipment is now available, such as, portable PASCO force platforms (Pasco, Roseville, California, USA) that are capable of sampling at rates of up to 1000 Hz. Good to strong reliability of this assessment has been reported in elite male soccer players (CV = 4.3 - 6.3%) (53) and the test was sensitive to changes in performance following match induced fatigue at both angles recorded, indicating its practical usefulness in the assessment of isolated hamstring strength (53). However, the reliability and sensitivity of this test in youth populations is currently not known.

A limitation of the work of McCall et al. (53) is the test position, which may not replicate positions of high injury risk during sprinting (18) and the hamstrings role in resisting anterior tibial translation of the knee joint during cutting and landing manoeuvres. A recent investigation in elite male youth soccer players utilized an isometric hamstring test, whereby, subjects were positioned with their foot locked in a load cell secured to the floor (105). To standardize the hip position and replicate a more functional position of the hamstrings during the terminal swing phase of the running action, participants were asked to lay prone on a plinth, underneath a portable 45° wedge board. (105). Strong reliability was reported for measures of peak torque (ICC range = 0.80 – 0.91; SEM% range – 4.0 – 5.7%) and a minimal detectable change of between 11.1 and 15.9%. Such changes in strength or asymmetry have previously been associated with an increased risk of hamstring injury (22). However, caution should be applied when interpreting these findings as there is currently limited evidence to indicate the predictive validity of isometric tests, specifically in soccer players, and in particular within youth populations. Also, the relatively large minimal detectable change reported indicates that substantial differences would be required to observe a 'real' change following a targeted training program to reduce injury risk.

*Field-based hamstring strength tests*

A previous investigation of risk factors for hamstring injury in adult soccer players assessed injury history and included a Nordic hamstring strength assessment within a screening battery (28). The test was scored as either weak or strong based on the player's ability to hold the required body position during a Nordic hamstring curl beyond a 30° angle for 10 seconds. However, no association with increased risk of hamstring injury was identified and inter-rater reliability was weak (k = 0.24). More recently, the Nordic hamstring curl has been used to measure knee angular displacement via two-dimensional analysis, whereby, a greater knee angle prior to the moment where the athlete loses eccentric control may be indicative of heightened eccentric hamstring strength (96). The relationship between the break point angle (the angle at which the subject is unable to resist the gravitational moment) and isokinetic hamstring peak torque showed a significant correlation ($r$ = -0.80, $R^2$ = 65%) in male and female adult soccer players, but not the angle of peak torque). A limitation of this assessment is the requirement for testers to hold the athletes' feet during the movement: thus, issues regarding standardization of pressure, especially between testers, may affect test-retest reliability. Also, no data are available in youth populations.

A more sophisticated methodology has been proposed that assesses eccentric peak force and bilateral muscle balance during the Nordic hamstring curl exercise on an instrumented device with uniaxial load cells (69). Test-retest reliability of this device has been reported with recreationally active males displaying high to moderate reliability (ICC = 0.83 - 0.90; TE = 21.7 - 27.5 N; CV% = 5.8 – 8.5) (69). In adult male Australian rules football players, eccentric hamstring strength below 256N (risk ratio = 2.7; $p$ = 0.006) and 279N (risk ratio = 4.3; $p$ = 0.002) at the start and end of the preseason respectively increased the risk of future hamstring injury (70), while asymmetrical limb differences of > 10% did not significantly increase injury risk (70). It should be noted that in contrast to isokinetic measures, movement speed during Nordic hamstring curl assessments cannot be controlled, and it is not possible to determine the angle at which peak torque of the knee flexors occurs. In addition, comparative assessments between knee extensor and flexor strength to assess hamstring to quadriceps (H:Q) ratios cannot be easily administered, thus limiting the information available to identify this injury risk factor.

An alternative measure is the single leg hamstring bridge test that requires the athlete to position themselves in a supine position and place one foot on top of a box with the aim of performing as many repetitions as possible using a straight leg hip extension motion. A recent prospective study showed that young male Australian rules players who experienced a hamstring strain injury during the course of a season performed a significantly lower number of repetitions than the non-injured control group (32). However, there was a low overall injury rate and confounding factors were reported including, age and previous injuries, which are known risk factors for hamstring strain injury (28). This assessment could also be considered a test of muscular endurance as opposed to strength, and places a greater emphasis on the concentric function of the hamstrings.

Based on the current body of evidence, there is a paucity of valid and reliable field-based assessments to accurately measure quadriceps and hamstring strength and H:Q ratios in male youth soccer players. Also, the predictive validity of these assessments remains unclear and requires further investigation. An overview of the available research using youth populations to measure quadriceps and/or hamstring strength is summarized in *table 1*.

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## 3.0 Assessment of leg asymmetry

### *Single leg jumps and hops*

While there is currently a paucity of studies that have prospectively identified injury using single limb tests, unilateral tasks may be preferred to bilateral variations due to their enhanced sensitivity for determining asymmetrical deficits in neuromuscular control (106). Also, a variety of assessments may be warranted due to different task demands (vertical vs. horizontal) and increased sensitivity in detecting previously injured ACL patients (4). Furthermore, assessments of leg power across 3 directions (vertical, horizontal, and lateral) have shown non-significant relationships between tests in the various movement planes (41, 52, 55); thus, utilizing a range of assessments targeting multi-planar actions is warranted.

When interpreting thresholds of asymmetry, a limb difference ≥ 15% has been shown to negatively impact function and performance following injury in multi-sport participants aged between 14 and 25 (95); thus, asymmetries of this magnitude may be considered a pertinent risk factor. Between-limb differences corresponding to these values during a single leg countermovement jump are expected in 20-30% of the sample tested in healthy teenagers (17). Inter-limb asymmetries in uninjured youth athletes have also been measured during sprinting and are reported to range from 15-20% (93). In male youth soccer players, musculoskeletal imbalances > 10% have also been identified in the majority of the participants tested (24), which underlines that greater movement variability is evident in youth populations (33). Thus, further research is required in this cohort to examine if an asymmetry threshold exists that predisposes young soccer players to a greater risk of injury.

Commonly used single leg hop tests have reported strong reliability (ICC range = 0.89 – 0.99) including vertical jumps, single, triple, and crossover hops for distance, and a six-meter hop for time (3, 12, 15, 52, 55, 57, 74, 90). Of all the horizontal hop tests, standard error of measurement is consistently lowest in the single hop for distance (57, 87, 90) but the repeated hopping tests may display greater ecological validity for soccer players. The triple hop comprises a deceleration component followed by the application of concentric force and use of the stretch-shortening cycle (SSC). The ability to attenuate force during a single limb stance and subsequently regenerate and direct motion may be a key factor for reducing injury risk (51). This test has also been established as a strong predictor of vertical jump height ($R^2$ = 69.5%) and isokinetic measures of hamstring and quadriceps peak torque ($R^2$ = 49% - 58.8%) (37). Practitioners should be cognizant of the fact that rebound tasks performed in a unilateral stance are highly demanding and elicit substantial eccentric loading, which may not be suitable for youth subjects with limited exposure to plyometric training. The single hop for distance may be more appropriate as part of an initial screen in younger athletes, and once subjects have developed an appropriate training age and requisite technical competency, the triple hop can be introduced. The single hop for distance has also been used recently to identify young students who possess a greater risk of hamstring strains (34), a frequently occurring injury in male youth soccer (80). The authors suggested that the requirement to stick and hold the landing involves a substantial deceleration component; thus, increasing the eccentric demand of the hamstrings (34).

In addition to horizontal jumping, single leg countermovement jumps should also be considered due to the frequency of such tasks during match play. This test has shown strong reliability in recreational youth athletes for peak force and peak power variables (ICC range = 0.88-0.97) (17). With respect to asymmetry, statistically significant differences for peak force and peak power were observed on the dominant leg in boys (17), which previous literature has suggested may be indicative of an increased risk of soccer injury in male players (14). The ability of this test to detect functional limitations after knee ligament reconstruction in adult males has also been confirmed, with authors reporting that the single leg countermovement jump height was the only assessment to identify an asymmetry > 15% from a battery of single leg hop tests 54 weeks after surgery (77). Therefore, the single leg countermovement jump height could conceivably be included as part of a return to play criteria following a knee ligament injury in male youth soccer players. Less information is readily available to confirm the association between asymmetrical landing forces and injury risk and this relationship warrants further investigation. If impact forces on ground contact exceed the force absorption capabilities of the involved musculature, additional loading will be diverted to other soft tissue structures, heightening the risk of ligamentous injury (40). Thus, it may be prudent to examine variables that quantify the magnitude of the forces experienced and the speed of loading as a means of determining the rate of stress application to both active and passive restraints.

Asymmetry has also been identified in male youth soccer players using alternative tasks including an overhead squat screen (2) and range of motion assessments (24). In high school basketball players, asymmetrical reach scores > 4 cm in the anterior reach direction of the y-balance test have also detected athletes at a 2.5 times greater risk of injury (78). Further research is required to examine the within-subject variation of selected test measures and their associations with injury risk in male youth players. An overview of the available research utilizing assessments to measure leg dominance in youth populations is summarized in *table 2*.

***** *insert table 2 near here* *****

**4.0 Assessment of frontal plane knee control (knee valgus)**

While the gold standard for kinematic assessment of knee valgus is via three-dimensional motion analysis, this approach requires specialized equipment and labour intensive data collection. Alternative time-efficient and non-invasive clinic-based methods have been proposed using two-dimensional video analysis, which are significantly correlated with more sophisticated laboratory techniques (61, 63, 71). An overview of the predominant assessments to measure ligament dominance is included below and those used in pediatric populations are provided in *table 3*.

*Clinic based landing assessment tool*

A nomogram predicting high knee abduction status derived from the landing phase of a drop vertical jump in adolescent female athletes has recently been developed (61). Variables within the nomogram include: knee valgus motion, relative quadriceps recruitment, knee flexion range of motion, tibia length, and mass. The authors validated this assessment tool as a clinician-based tool that can be administered in a field-based environment (63) (*figure 1*).

****** insert figure 1 near here ******

This method requires two standard video cameras positioned in the sagittal and frontal planes; and moderate-high agreement has been reported between the laboratory nomogram and the clinic based tool (ICC range 0.66 - 0.99) (61, 63). However, this method was validated using female subjects and no data is available for male youth soccer players. Also, the nomogram suggests the use of isokinetic measures of concentric knee extension/flexion to establish H:Q ratios and if this equipment is not available, then a surrogate measure of H:Q ratio can be used based on the athletes body mass (61). Caution should be applied using this approach with male youth soccer players, as while this increases efficiency the use of the surrogate calculation with males, and in particular male youths at different stages of growth and maturation may not be suitable. In addition, the use of the functional H/Q ratio (ECC Ham: CON Quad) may be more ecologically valid as purely concentric measures are not reflective of true knee joint movement that only allows eccentric muscle actions to be combined with concentric quadriceps actions during extension and flexion respectively (1, 20, 35).

*Landing error scoring system (LESS)*

The LESS is a clinical assessment tool of an individual's jump-landing biomechanics using two-dimensional analysis with cameras positioned in the frontal and sagittal planes (71). This method was validated against three-dimensional motion analysis and force plate diagnostics during a drop vertical jump (71). The LESS score was originally determined using a count of 17 technique errors based on a standardized checklist, which is calculated retrospectively (71). Participants with higher scores (where a score $> 6$ was rated as poor and $< 4$ was excellent) have displayed kinematics indicative of poor landing mechanics (71). More recently, this method was able to differentiate between patients with a history of anterior cruciate ligament (ACL) reconstruction and healthy controls (7). Of note, greater lateral trunk flexion on landing was displayed in the ACL reconstruction group, which could be representative of a lower limb avoidance strategy (7). Prospective evaluation in youth athletes has shown mixed findings. Following baseline screening during preseason, elite youth soccer players were prospectively tracked throughout the course of a soccer season (73). Altered landing kinematics were reported in players who sustained an ACL injury versus non-injured controls; however, a small number of injuries were recorded during the study period (7 injuries from a cohort of 829 players), and only one of the injuries sustained was to a male player. In a sample of high school and collegiate athletes monitored over a three-year period, no association was reported between LESS score and the risk of sustaining an ACL injury (97). Due to inconsistencies in the aforementioned research, further investigation is warranted to validate this method in male youth soccer players.

In adult subjects, inter-rater and intra-rater reliability of the LESS has been reported as strong to very strong respectively (ICC = 0.84; SEM = 0.71; ICC = 0.91; SEM = 0.42) (71). In youth athletes, strong reliability (ICC = 0.97 – 0.92) has been shown for intra and inter-rater reliability respectively (97). A modified version of this assessment has also been developed (*figure 2*); reducing the number of scored items to a 10-point criteria (72) and inter-rater reliability (ICC = 0.72 – 0.81; SEM = 0.69 – 0.79) was comparable to the original method, which may enhance its practicality of use. Cumulatively, the LESS can be considered a valid and reliable tool to identify subjects with altered landing mechanics reflective of high injury risk. However, inconsistencies are present in the ability of this measure to prospectively predict injury risk in male youth athletes. Also, the use of the aforementioned scoring classification system (i.e. $< 4$ = excellent, versus $> 6$ = poor) in clinical settings may not be appropriate for all male youth soccer players as their results were based on quartiles from military participants, including both male and female adults (71).

******* insert figure 2 near here *******

*Tuck jump assessment*

The repeated tuck jump assessment is a clinic-based tool to identify plyometric technique flaws indicative of high injury risk (60, 64). Performance on this test has been suggested to provide an indication of quadriceps dominance, ligament dominance, leg dominance, and trunk dominance, all of which are known risk factors for lower limb injury (60, 62, 84). The protocol requires repeated tuck jumps to be performed in place for a period of 10 seconds and subjects are assessed using a ten-point rating scale (*figure 3*) with a greater a number of deficits indicating increased injury risk (60). To increase accuracy, two-dimensional video analysis can be used to capture the test and grade each player's technique retrospectively.

***** *insert figure 3 near here* *****

This assessment has been used previously to quantify the effectiveness of in-season neuromuscular training in comparison to a control group that only followed a soccer training program (46). While both groups significantly reduced their tuck jump assessment score, no differences were observed between groups. Also, more recently tuck jump performance was measured before and after a task specific feedback intervention (64, 100). Augmented feedback throughout the programme was shown to be more effective in reducing plyometric technique errors measured in the tuck jump than a control group who undertook a matched training intervention but were offered no specific feedback on their performance (100). This training approach has also been shown to be effective at reducing vertical ground reaction forces and frontal plane projection angles during a drop vertical jump assessment (58). No data are currently available in male youth soccer players to measure the effectiveness of training interventions or to determine the ability of this test to prospectively predict injury risk.

Initial pilot studies indicated moderate-strong inter-rater reliability for the tuck jump assessment (ICC = 0.72 – 0.97) (60). Intra and inter-tester reliability have also been reported and showed strong agreement (kappa measurement (k = 0.88)) (38). In elite male youth soccer players, acceptable typical error between test sessions for tuck jump total score (TE = 0.90 – 1.01) has been shown; however, analysis of the individual components that comprise the total score indicated that knee valgus was the only criteria to reach substantial agreement across test sessions (85). Thus, while total score can be reliably measured, accurately identifying the relevant risk factors remains uncertain, and restricting the analysis to knee valgus for test re-test comparison seems most appropriate (85).

*Considerations for selecting the type of jumping task*

When using a drop vertical jump assessment with youth subjects, practitioners must consider what the most appropriate drop height is for their athletes. Intuitively practitioners may wish to standardize the box height at 30 cm to allow comparisons with previous research (5, 31, 61, 63, 67, 71, 81, 95). However, when screening athletes for injury risk, different heights may provide either insufficient or excessive forces from which to elicit an appropriate response and this may be magnified when working with large groups of young athletes who all possess varying neuromuscular qualities. One approach to overcome this constraint is to assess landing mechanics following the completion of a maximal vertical jump. Alternatively, analysis of the second landing could be performed, providing a height reflective of their individual neuromuscular ability and a more perturbated landing position. In adolescent female basketball players, no significant differences were shown in peak vertical ground reaction forces between landings, but greater asymmetry was present in the second landing and this was combined with a higher center of mass position (6). The authors suggested that these factors are more reflective of sporting activities and heightened injury risk.

The validity of the drop vertical jump as a screening tool for predicting ACL injury risk has recently been examined in elite female soccer players (47). Test measures included both kinetic and kinematic risk factors and it was shown that medial knee displacement was associated with an increased risk of ACL injury (odds ratio, 1.40). However, poor sensitivity and specificity of this measure was reported using a receiver operating characteristic curve indicating that this test cannot predict ACL injuries in this cohort (47). Practitioners should also consider the ecological validity of drop vertical jump assessments. In more functional tasks, such as repeated jumping tests, landing heights are equivalent to those regularly demonstrated by individuals during match play and forces are controlled via a preceded shortening of the involved musculature which are required to perform propulsive motions (i.e. the initial jumping action). This type of assessment may better represent the ability of the neuromuscular system to provide adequate stabilization and force attenuation in response to each individual's jumping capabilities. It could also be inferred that drop jumping tasks may artificially induce feed-forward stabilization mechanisms, which is a learnt skill, developed throughout childhood and adolescence (28). The pre-planned nature of these assessments do not require a stimulus-response component that are characterized by perturbations to the body's centre of mass, which in turn increases landing forces and compromizes the integrity of joints and soft tissue structures (8). Thus, the repeated nature of the tuck jump assessment provides some inherent perturbation and may more accurately reflect the movement demands and high-risk mechanics involved in competition (85).

A final consideration in the assessment of dynamic valgus is the frequent use of bilateral tasks and the lack of consideration for the positioning of the trunk on landing. A recent prospective cohort study showed that isolated measurement of knee valgus during a single leg drop vertical jump was not a predictor of non-contact knee injury (25). Conversely, the combination of knee valgus and ipsilateral trunk motion did predict injury in female athletes (25). No comparisons were made with bilateral tasks; however, it could be suggested that for the assessment of dynamic knee valgus, practitioners should consider using single leg tasks and assess both proximal (trunk/hip) and distal (foot) factors to enhance the predictive value of jump-landing assessments in their ability to identify youth players who display high risk kinematics.

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## 4.0 Assessment of trunk dominance

The assessment of core proprioception has commonly involved the use of specialised equipment to isolate motion of the lumbar spine, and has shown moderate (ICC = 0.58 – 0.61) reliability (107, 108). Trunk displacement was greater in collegiate athletes with knee injuries than un-injured athletes and was also shown as a predictor of knee ligament injury (108). However, these measures were derived during artificial conditions and postures in which the pelvis is immobilized, thus reducing ecological validity. Furthermore, highly specialized and costly equipment is required, limiting their application to larger scale youth athlete screening programs.

Limited data are available to report the validity and reliability of field-based core stability tests in male youth athletes. In adults, a number of trunk dominant exercises and standing based tasks including; prone bridge, single leg squat, and lateral step down have shown poor intra-observer reliability (ICC range 0.09 – 0.51) (104). Trunk muscular endurance assessments such as isometric holds in a variety of positions have displayed stronger reliability (ICC range 0.97-0.99) (54); however, the ecological validity of such measures may be questioned based on their prolonged isometric actions and non-functionality. This is confounded by reports of weak to moderate relationships (ICC range = 0.37-0.62) between performance on the aforementioned core tests and a range of athletic measures (65). Leetun et al. (49) used a modification of these protocols with additional measures of hip abduction and external rotation strength. Regression analysis demonstrated that hip external rotation strength was the only predictor of injury status (OR = 0.86); therefore, using isolated measures of core stability to infer lower limb injury risk and performance measures provokes questionable validity. Alternatively, movement abnormalities indicating a loss of core control may be detectable using more dynamic approaches, for example during the tuck jump assessment (60) or the LESS test (71).

## 5.0 Assessments of dynamic stability

Studies that have examined balance abilities in youth populations have predominantly utilized static tasks (9, 23, 66, 75, 89, 99). Static balance postures are not reflective of the dynamic nature of soccer activities during which injuries occur. This is supported by previous data that identified weak relationships between static and dynamic tasks used to assess balance performance in male youth soccer players (75). Thus, assessment of dynamic balance and stability should be comprised of more functionally relevant tasks indicative of the dynamic actions that regularly occur in soccer. Two common methods are time to stabilization (27, 30, 91, 92) and the star excursion or y-balance assessment (56, 78, 79).

*Time to stabilization (TTS)*

Measurement of TTS involves the use of a force plate to quantify the speed in which individuals stabilize after a landing task (27, 91). Although both drop jumps (30) and single leg drop landings (26) have been used, the most common form of assessment is a horizontal single leg hop and stick (36, 59, 91). Single leg landing assessments may be more ecologically valid for soccer players and are also indicative of greater injury risk (51, 102, 106). Therefore, assessing single leg landing kinetics may be a more appropriate measure of injury risk.

Two prominent methods of analysis have been applied to quantify TTS. The first involves scanning the components of ground reaction force from the last two windows of the final 10 seconds of recorded data during a 20 second static hold following landing, with the smallest ground reaction force range accepted as the optimal range variation (91). The data is then rectified and from the moment of peak ground reaction force an unbounded third order polynomial is fitted, with TTS determined as the point in which this polynomial transects the horizontal range variation line (91) (*figure 4*). The second method quantifies the time taken for an athlete upon landing to reach and stabilize within a ground reaction force range representative of 5% of the athlete's bodyweight for a period of one second (*figure 5*) (27, 30). For younger athletes, the requirement to spend prolonged periods standing still on the force plate will likely demonstrate greater postural sway, thus affecting the ground reaction force range. Consequently, the method of Flanagan et al. (30) may be more suitable for younger populations. Furthermore, the shorter recording period (7 seconds) as used by Flanagan et al. (30) has implications for testing a large number of athletes, particularly youth athletes who may demonstrate lower levels of concentration. Also, the requirement to analyze the vertical force only permits the use of portable and cost effective force plates (Pasco, Roseville, California, USA), further enhancing their utility

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The validity of this assessment has previously been shown with TTS profiles accurately detecting the difference between healthy controls and those with a history of ankle injury (92) and ACL deficiency (103). Strong reliability data has also been reported for TTS during a single leg hop and hold task (ICC = 0.87-0.97) (19) for both dominant ($r$ = 0.82) and non-dominant ($r$ = 0.88) limbs (59). This measure has also been used as an outcome variable for intervention studies, showing significant reductions (i.e. stabilizing earlier) following an injury prevention programme in both male youth athletes (26) and male youth soccer players (43).

A useful feature of this assessment is that it involves both vertical and horizontal displacement, and stabilization mechanisms inherent to soccer (16). Standardization procedures to control for jump distance have either normalized horizontal displacement to an arbitrary figure of 70 cm (91), or to leg length (36). Significantly longer TTS were shown in subjects using the leg length standardization procedure in comparison to the predetermined 70 cm protocol (36). Using anthropometric measures to determine jump distances might subsequently over- or under-estimate performance of a child or adolescent. During a maximal single leg hopping task, an athlete may be capable of much greater jump distances than that of their leg length. Such feats of athleticism are likely to be replicated under the conditions of competitive match play; thus, an individual's inherent risk of injury is likely a product of how far they can jump and their ability to attenuate the resultant ground reaction forces on landing. A more appropriate method may be to standardize hop distance using a percentage of maximal hop performance to represent their individual neuromuscular capabilities (Read et al., in press consistency paper).

*Star excursion or y-balance test*

Another unilateral task used to assess dynamic stability is the star excursion balance test (78). The original version of this test required athletes to stabilize in a unilateral stance and reach in eight specified directions with their opposite limb. The test is graded by marking the reach distance achieved in each direction with scores normalized to leg length (78). This test has been used as an injury predictor in male youth basketball players, where subjects who recorded an anterior right-left reach difference > 4 cm displayed a 2.5 times greater risk of lower extremity injury (78). Furthermore, in the female group, subjects with a composite reach distance < 94% of their limb length were 6.5 times more likely to sustain a lower extremity injury (78). More recently, a modified version of this assessment has been proposed, namely the y-balance test, which only requires athletes to reach in 3 directions: anterior, posteromedial and posterolateral

(799). In adults, the posteromedial reach direction has shown equivalent accuracy to all eight reach directions in its ability to identify subjects with chronic ankle instability (39). Significant correlations have also been reported between both posteromedial and posterolateral reach distances and hip abduction and extension strength respectively (42).

Early investigations in adults demonstrate moderate to strong reliability for the star excursion balance test (ICC range 0.67-0.86) (45). The authors suggested that task complexity was responsible for the moderate values, highlighting the need for adequate familiarization. More recent reports confirmed that excursion distances stabilized after four trials (56), with greater familiarization resulting in stronger reliability (ICC range = 0.84-0.92; SEM = 2.21–2.94%, smallest detectable differences = 6.13–8.15%). To ensure time-efficiency in screening a large number of youth athletes, this approach has been modified with practice trials performed in a group setting away from the instrumented device, with an additional practice trial conducted on the y-balance kit (29). Moderate to strong reliability was reported in school children of different ages (ICC = 0.71 – 0.88) (29). In youth soccer academies where a large number of athletes must be screened, the prioritization and use of the anterior reach direction may also be more appropriate to detect athletes who demonstrate asymmetrical reach distances and subsequently display a heightened risk of injury (78). Cumulatively, these findings suggest that the y-balance test may be a reliable and sensitive protocol, which is simple to administer and cost effective for the screening of youth athletes.

## 6.0 Summary

In this review, the merits of a number of field-based assessments that may be used to screen lower extremity neuromuscular control in male youth soccer players have been examined. Their suitability for use within the context of a soccer academy has also been critically appraised. A test battery has been provided (table 4) to show which field-based tests from this review have prospectively identified athletes at a greater risk of injury. Clinical interpretation and limitations of their use have also been included to aid practical application. However; due to the paucity of data available in male youth athletes, and in particular soccer players, this battery should be used with caution in this cohort. It should also be acknowledged that other tests included in this review may provide useful data for practitioners and could be included as part of an injury risk screening battery but their validity has yet to be examined. Further investigations are required to analyze the reliability and validity of these assessments

**Key Points**

- Field-based tests of neuromuscular control provide a reliable option for the assessment of injury risk in youth athletes, however there is a paucity of data available in male youth soccer players
- Functional hopping tasks can be used effectively to screen male youth athletes, and practitoners should consider using more than one test to enhance their sensitivity in identifying players who display side to side differences that may be indicative of reduced function and performance

- Asymmetry is apparent in male youth soccer players and assessment of this risk factor should include a variety of jumps, hops and dynamic balance tasks for prospective injury risk prediction and determination of appropriate thresholds for a safe return to play
- A range of valid and reliable jump-landing based assessments are available using two dimensional video analyses. Recent data show that aberrant landing kinematics can prospectively predict injury risk in youth athletes but this is not consistent across all studies
- Measures of dynamic balance may predict lower extremity injury in male youth athletes and practitioners should also consider the inclusion of dynamic jump-landing tasks due to greater ecological validity

**Compliance with Ethical Standards**

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

**Conflicts of interest,**

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

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**Table 1** Assessments of quadriceps dominance in male youth athletes

| Reference | Subjects | Measurement Tool | Summary of findings |
|---|---|---|---|
| Herbert et al. 2011 | 74 school-age boys and girls (age 4-17) | Assessment of reliability and concurrent validity between the Isokinetic and hand held dynamometer | Mean intra and inter-rater reliability (ICC range = 0.67 - 0.98). SEM varied from 0.5 to 6.0 Nm and was highest for the hip extensors and ankle plantar-flexion. Mean concurrent validity (ICC) varied from 0.48 to 0.93 |
| Hill et al. 1996 | 18 boys and 7 girls (aged 9-11) | Relationships between isokinetic and hand held dynamometry measured at different joint angles and movement speeds | Isometric strength was able to predict low-velocity dynamic strength with moderate-high reliability (ICC range r = 0.77 – 0.82). Greater speeds displayed lower relationships (120°$s^{-1}$, ICC range r = 0.61 – 0.71; 180°$s^{-1}$ 0.46 – 0.66) |
| Stemmons et al. 2001 | 17 healthy children (aged 11.1 ±2.4) | Test re-test reliability measurements of hand held dynamometry in healthy children and those with down syndrome | Reliability for normal children (ICC = 0.94-0.95, SEM = 17.6-22.7N). Lower ICC and higher SEM were reported for children with down syndrome |
| Freckleton et al. 2013 | 482 semi elite Australian Rules players (age range 16–34 years) | Single leg hamstring bridge test (SLHB). Pre-season screen and season monitoring of Hamstring Injuries. | Reliability of SLHB (ICC =0.77–0.89; inter-tester ICC = 0.89–0.91). Players sustaining a right hamstring strain during the season had a significantly lower mean right SLHB score ( p=0.029), were older ( p=0.002) and more likely to have sustained a past right hamstring injury (p=0.02) |
| Wollin et al. in press | 16 elite male youth soccer players (age 16.81 ± 0.54 years) | Intra and inter-day reliability of a prone single leg isometric hamstring test using a calibrated load cell | Good to strong inter-test reliability was reported (ICC range = 0.80-0.91; SEM% range = 4.3 - 5.7%). A minimal detectable change of 11.8 – 15.9% was reported to accurately determine a clinical outcome following an intervention. |

**Table 2** Assessments of leg dominance in male youth athletes

| Ref | Subjects | Assessment | Summary of findings |
|---|---|---|---|
| Atkins et al. (in press) | 74 Youth males, assigned to performance groups according to chronological age (Under 13- 17). | Overhead deep squat on a twin Force Plate system measuring peak ground reaction force (PGRF) | Significant differences (p ≤ 0.05) were identified between right and left side PGRF for all groups except the youngest (U13) and oldest (U17). Non-dominant 'sides' showed the highest levels of PGRF across all groups. The magnitude of PGRF was not significantly different both within and between groups, except for the left side in the U13 to U15 groups (p = 0.04). |
| Ceroni et al. (2012) | Youth males (n=117 age 13.33 ± 1.93) & females (n=106 age 13.68 ± 1.87) | Single leg vertical jump on a force plate without arm swing measuring peak vertical force (PVF) & power (PW) | ICC of test measures (range = 0.88-0.97) with 20–30% showing a difference of >15% between limbs. Between group asymmetry differences (>15%) were evident: females PVF = 25.5%; PW = 32.7%; Males PVF = 21.4%; PW = 21.4%. Statistically significant differences for peak force and power on the dominant leg were reported in boys only. |
| Plisky et al. (2006) | 235 high school basketball players | Pre-season star excursion balance test measures and daily injury report to document time loss injuries over a season | Logistic regression models indicated that players with an anterior right/left reach distance difference >4 cm were 2.5 times more likely to sustain a lower extremity injury (P<.05). Girls with a composite reach distance <94.0% of their limb length were 6.5 times more likely to have a lower extremity injury (P<.05). |
| Reid et al. (2007) | 42 patients aged 15 to 45 years of age, who had undergone ACL reconstruction | 6m timed hop, single leg hop, cross over hop and triple hop for distance 16 weeks after surgery and a further follow up session 6 weeks later | ICC of all hop tests (range = 0.82 – 0.93), SEM (3.04 – 5.59%), MDC (7.05 – 12.96%). Statistically greater changes in hop scores were reported on the operative vs. the non-operative leg. |
| Daneshjoo et al. (2013) | 36 male professional soccer players (age 18.9 ± 1.4 years | Biodex isokinetic dynamometer measures of peak torque (PT) for the hamstrings and quadriceps | PT of both hams & quads in the non- dominant leg at all angular velocities showed non-significant higher tendencies than the dominant leg. Asymmetry deficits were abnormal (>10%) at all angular velocities, with 97.2% reported to have at least one musculoskeletal abnormality >10%. Also flexibility in the non-dominant leg was lower than the dominant leg. |
| Noyes et al. (1991) | 40 male and 27 female recreational subjects (age range 16-48) with a history of ACL injury | KT-1000 arthrometer and biodex lower extremity @ 60 &300 d/s and 4 hop tests single leg hop for distance, timed hop, triple hop for distance, cross-over hop for distance. | 50% of subjects had limb asymmetry >15% on one of the single hop tests. When the results of two hop tests were combined, number of subjects with asymmetry >15% increased to 62%. Statistical trends were also noted between limb asymmetry on the hop tests and low velocity quadriceps isokinetic test results but not fast velocity. |

**Table 3** Assessments of knee valgus in male youth athletes

| **Reference** | **Subjects** | **Measurement Tool** | **Summary of findings** |
|---|---|---|---|
| Paterno et al. (2010) | 56 subjects (n = 35 female: 25 male; age 16.41 ± 2.97) | Drop vertical jump (3DMA) and force plate measures of ground reaction force; postural stability using a Biodex balance system and anterior/posterior knee laxity using a CompuKT | Integrated landing prediction model for ACL injury reported high sensitivity (0.92) and specificity (0.88). Subjects who sustained a second ACL injury had altered landing mechanics and deficits in postural stability. |
| Quatman et al. (2005) | 5 pubertal and prepubertal subjects. (No specific data given on these subjects) | Drop vertical jump (3DMA) and vertical ground reaction force (VGRF) using 2 force plates. | Reliability statistics for repeated measures across three sessions included: maximum VGRF at landing (ICC = 0.89), maximum VGRF at takeoff (ICC = 0.98) and maximum vertical jump height (ICC= 0.98) |
| Ford et al. (2003) | 81 High school subjects (males age, 16 ± 0.2; Females age, 16 ± 0.2) | Drop vertical jump (3DMA) | Strong reliability was reported for both knee separation distance at maximum valgus angle (ICC = 0.92) and the difference between knee valgus angle at initial contact and maximum valgus angle (ICC = 0.84). |
| Noyes et al. (2005) | 325 females (age; 14.1 ± 1.7; range 11-18 years) and 130 male athletes (age; 14.6 ± 2.0; range 11-19 years) | Drop vertical jump 2D analysis | Test-retest reliability for hip separation distance was strong (ICC = 0.96 pre-land; land, 0.94; takeoff, 0.94). Following a 3 days p/wk. 6 week neuromuscular training program. |

**Table 4. Field-based screening battery of tests that have** prospectively identified athletes at a greater risk of injury

| Risk Factor | Selected Test | Testing Equipment | Clinical findings | Limitations |
|---|---|---|---|---|
| **Reduced strength levels of the posterior chain** | Nordic hamstring curl | Nord board | Eccentric hamstring strength < 256 N increases risk of future hamstring strain (Opar et al., 2015) | 1) Not validated in male youth soccer players; 2) expensive test equipment |
| | Single leg hamstring bridge (SLHB) | Step up or plyometric box | SLHB scores ≤ 20 reps on the right leg increases risk of hamstring strain (Freckleton et al., 2011) | 1) Not validated in male youth soccer players; 2) Test is more reflective of muscular endurance |
| | Hip external rotation | Hand held dynamometer | Scores < 18 % body weight increase the risk of lower extremity and back injury (Leetun et al., 2004) | 1) Not validated in male youth soccer players |
| **Lower unilateral force production and control** | Single leg hop for distance (SLHD) | Tape measure | Reduced hop distances associated with greater risk of hamstring injury (Goosenes et al., 2015) | 1) Not validated in male youth soccer players |
| **Aberrant landing mechanics** | Single leg vertical jump | Two dimensional video camera | Sum of knee valgus and lateral trunk motion angles ≤ 178◦ increases the risk of ACL injury (Dingenen et al., 2015) | 1) Not validated in male youth soccer players |
| | Landing error scoring system (LESS) | Two dimensional video camera | LESS score < 5 increased injury risk. Most predictive criteria: trunk-flexion, hip-flexion, knee flexion and joint displacement, trunk flexion at initial contact, and externally rotated foot position (Padua et al., 2015) | 1) Scoring criteria is subjective thus potential for increased rater error |

| | | | | |
|---|---|---|---|---|
| **Asymmetrical dynamic balance** | Y-Balance (anterior reach direction) | Y-Balance kit or tape measure | Asymmetrical anterior reach scores > 4 cm places athletes at 2.5 x greater risk of injury (Plisky et al., 2006) | 1) Validated in male youth basketball players; thus, requires examination in soccer |