The Journal of Strength and Conditioning Research™

Can a Standardized Visual Assessment of Squatting Technique and Core Stability Predict Injury?

Siobhán O'Connor, Noel McCaffrey, Enda F. Whyte, and Kieran A. Moran

School of Health and Human Performance, Dublin City University, Dublin, Ireland

Abstract

O'Connor, S, McCaffrey, N, Whyte, EF, and Moran, KA. Can a standardized visual assessment of squatting technique and core stability predict injury? *J Strength Cond Res* 34(1): 26–36, 2020—This study examined whether a standardized visual assessment of squatting technique and core stability can predict injury. Male adolescent and collegiate Gaelic players (n = 627) were assessed using the alternative core/trunk stability push-up test and a developed scoring system for the overhead squat and single-leg squat (SLS) that examined both overall impression and segmental criteria. A single summative score from the overall impression scores of all 3 tests was calculated. Sustained injuries were examined over a season. Results indicated that the single summative score did not predict those that sustained a lower-extremity injury, trunk injury, or whole-body injury, and receiver operating characteristic curves were also unable to generate an optimal cutoff point for prediction. When segmental criteria were included in multivariate analyses, the tests were able to predict whole-body injury ($p < 0.0001$) and lower-extremity injury ($p < 0.0001$). However, although specificity was high (80.6%, 76.5%), sensitivity of the models was low (40.2%, 44.2%). The most common score was "good" for the overhead squat (46.4%) and SLS (47.6%), and "good" and "excellent" for the alternative core stability push-up test (33.5%, 49.1%), with "poor" core stability increasing the odds of sustaining a lower-extremity injury (odds ratio = 1.52 [0.92–2.51]). The findings suggest that although segmental scoring could be incorporated by strength and conditioning coaches and clinicians, they should be used predominantly as a preliminary screening tool to highlight players requiring a more thorough assessment.

Key Words: overhead squat, single-leg squat, alternative trunk stability push-up test, Gaelic games

Introduction

Gaelic games (Gaelic football and hurling) are 2 field sports predominantly played in Ireland. Gaelic football is similar to Australian Football, and hurling can be described as a mixture of field hockey and lacrosse (47). Similar to other field sports, they require players to complete continuous light-to-moderate aerobic activity with repeated high-intensity anaerobic activity interspersed throughout (20). Injuries in Gaelic games are frequent, accounting for 61.8, 25.1, and 13.2 injuries per 1,000 hours in elite (7,44), collegiate (47), and adolescent (45) Gaelic players, respectively. The injury burden to players is considerable, particularly to the knee and ankle, with 80.8 and 52.8 days absent per 1,000 hours noted in collegiate and Gaelic footballers, respectively (47). Financially, an average claim costs the governing body for Gaelic games €1,158.40, and just under 65 million euro was paid out in claims between 2007 and 2014 (50). These highlighted socioeconomic costs of injury in Gaelic games indicate that priority should be placed on reducing injury risk.

Preseason screenings can be used to evaluate a player's ability in selected tasks with the aim of identifying risk factors for injury. This facilitates the introduction of preventative strategies, where necessary, to reduce the likelihood of subsequent injury (37). By assessing global movement patterns during functional tests, the synchrony of the neuromuscular control, range of motion, strength, endurance, balance, and coordination required to complete the movement can be examined (12,34). Although 3-dimensional (3D) motion analysis is considered the gold standard method for examining kinematics, it is generally not available to coaches and clinicians. It uses expensive equipment and can be time-consuming to complete, both of which limit its application to large-scale preseason screenings (41). Research recommends that tests and methods of assessment used in preseason screenings should be time efficient, simple to execute, and use field-based tests that require minimal and inexpensive equipment to maximize compliance (25,26,37). Thus, visual assessments are commonly used to examine risk factors for injury. However, it is critical to identify standardized visual assessments of field-based screening tests that can accurately predict injury.

The overhead squat is a commonly used screening test and is included in accepted screening methods, such as the Functional Movement Screen (FMS) (18) and National Academy of Sports Medicine (NASM) screening (15). The overhead squat was found to be a valid (12) and reliable (42,53,56) method of examining functional movement. It challenges multijoint mobility and control in an attempt to gain an understanding of the person's movement quality (12,17). Current research has reported contradictory findings on the ability of the overhead squat to predict injury. The overhead squat rated using the FMS criteria was found to significantly predict musculoskeletal injury in firefighters {odds ratio [OR] = 1.21 (95% confidence interval [CI]: 1.01–1.42)} (11), noncontact injuries in professional soccer players (p = 0.0128) (51), and contact injuries in professional rugby players (injured = 1.6 ± 0.8 vs. noninjured = 2.1 ± 0.4, Cohen's d = 1.04) (55) highlighting its use as a screening tool. However, only Tee et al. (55) examined the sensitivity and specificity of the overhead squat, and in combination with the in-line lunge and active straight leg raise, reported high specificity (83%), but lower sensitivity (52%). By contrast, no significant

Address correspondence to Dr. Siobhán O'Connor, siobhan.oconnor@dcu.ie.

Journal of Strength and Conditioning Research 34(1)/26–36

association between the FMS overhead squat and noncontact injury in Division 1 athletes (58) was noted, and other studies did not examine the relationship between individual tests within the FMS and subsequent injury (13,27,32,43). The ability of the overhead squat to predict injury in Gaelic games has not yet been examined. In addition, a challenge related to injuries that occur in field sports, including Gaelic games, is that mechanisms of injury are not always bilateral and cannot necessarily be replicated by the bilateral overhead squat exercise (51). In fact, both NASM (15) and Rusling et al. (51) suggested that the single-leg squat (SLS) should also be included in preseason screenings to provide an overall indication of movement quality (4) more applicable to field sports. The SLS is also considered more demanding than the overhead squat, potentially facilitating easier identification of any abnormal movement pattern present (38). In addition, motor control assessed by the SLS and the overhead squat were found to statistically predict nontraumatic injuries in NCAA Division 1 athletes examined prospectively over 3 seasons ($p = 0.03$) (28). However, the accuracy of the model was not reported. To date, limited research has examined whether the SLS predicts injury (39), and it has yet to be investigated in Gaelic games.

Although an "overall" assessment of the overhead squat movement pattern is common, (such as the FMS scoring criteria), the inclusion of a segmental level scoring system, where individual components of the squatting technique are assessed (such as knee alignment or depth of the squat for the overhead squat and SLS), could provide additional information on squatting technique. This may identify segment-specific predictors of injury, which could ultimately allow for more targeted prescription of corrective exercises. Thus, the utilization of a combined overall and segmental criteria scoring of both the overhead squat and SLS is a novel method of potentially enhancing the accuracy and predictive ability of these preseason screening tests.

Core stability provides a stable base for movement of the extremities, maintains the integrity of the spinal column, and provides resistance to perturbations; it requires adequate hip and trunk muscle capacity alongside appropriate motor control (62). Although there is a lack of consensus on a precise definition of core stability (8), it is commonly considered that core stability is an important factor in reducing injury risk in athletes (35). Although poor core stability (assessed by trunk control) has been shown to increase the risk of knee injuries in female athletes (63,64), overall, there is limited research demonstrating it is a risk factor to injury (62). Specifically, its ability to predict injury in male Gaelic games has yet to be examined.

The alternative trunk stability push-up test, adapted from the trunk stability test used in the FMS (17), is a simple and time-efficient functional screening test examining core stability for the athletic population (46). For the purpose of this article, the alternative trunk stability push-up test will be called the alternative "core" stability push-up test for clarity of terms. It has been suggested that the alternative core stability push-up test is more appropriate for assessing athletic populations because it examines core stability during a dynamic movement under functional loading (46) (rather than static control). It allows for greater subclassification by the inclusion of an additional step of lifting the right leg to reduce the stable base (46). Although the original trunk stability test has been found to predict nontraumatic injuries in professional soccer players (51) and injury in firefighters (OR = 1.30 [95% CI: 1.07–1.53]) (11), the individual test sensitivity and specificity were not presented. Other research found no relationship between the trunk stability push-up test and either severe injury in professional rugby union players (55) or noncontact injuries in Division 1 collegiate athletes (58). No research has yet examined the alternative core stability push-up test and its relationship to injury.

Previous screening tools have demonstrated varying levels of predictive ability in sporting populations. The FMS, for example, did not demonstrate predictive validity in active adult populations (21), with a recent meta-analysis noting high specificity (85.7%) but low sensitivity (24.7%) (21). In light of this issue and how common injuries are to the lower extremities and trunk in Gaelic games (45,47), it would be prudent to examine the ability of any screening tool to predict injuries to these specific anatomical regions, as well as to the whole body. In addition, the sensitivity and specificity should be examined to determine whether it is appropriate to use in this population.

Clinicians and strength and conditioning coaches tend to value and request a summative score from their screening that can accurately identify those at risk or not at risk of sustaining an injury. Screening tools, such as the FMS, have attempted to do this by using summative composite scores of all tests included in the screening tool. However, this presumes that all tests score as a unidimensional construct (31), which may not be the case. Previous research examining the FMS has demonstrated low internal validity, indicating that summative scores should not be used and instead focus should be placed on the individual scores rather than an overall score (9,31). Thus, it would be judicious to examine whether summative scores using the overhead squat, SLS, and alternative core stability tests or individual movement scores provide better predictive ability before recommending these tests to clinicians or strength and conditioning coaches.

This study therefore has 3 aims. The primary aim is to examine whether developed "overall" and "segmental" scoring systems for the overhead squat and SLS, and the alternative core stability push-up test, can predict lower-extremity injuries, trunk injuries, or whole-body injuries. The secondary aim is to present normative data for Gaelic game players for the overhead squat, SLS, and the alternative core stability push-up test. Finally, the third aim is to examine the relationship between all 3 screening tests to determine whether all 3 need to be used in a testing protocol.

Methods

Experimental Approach to the Problem

A cohort study design was implemented to examine whether standardized visual assessments of the overhead squat, SLS, and alternative core stability push-up test could predict injury in Gaelic game players. Previous research has found the alternative core stability push-up test to have excellent intertester (intraclass correlation coefficient [ICC] = 0.97) and good to excellent intratester reliability (ICC = 0.73–0.90) (32). Given that we developed the scoring system for the overhead squat and SLS, the reliability of these 2 tests was examined. The scoring system was developed by a biomechanist, sports medicine physician, and 2 certified athletic therapists. Content validity was established by discussing the limitations of previous scoring systems, highlighting the segmental areas that would need to be examined in the scoring system for corrective exercises to be prescribed. Consideration was also given to ensure the test was easy to administer, time efficient, and required minimal equipment. A 0–3 rating (0 = no issue, 1 = slight issue, 2 = moderate issue, and 3 = severe issue) was decided for each of the segmental criteria of the overhead squat and SLS: knees to toe alignment, knee medial alignment or knee valgus, toes facing outward, depth of squat, trunk forward flexion, and balance (Table 1). This scoring system was based on the relationships between joint position, loading, and the risk of injury. For example, correct knee alignment over the toes helps to reduce shearing forces at the knee joint during squatting (24). Increased knee valgus has been identified as a risk factor for knee injury (60), including noncontact anterior cruciate ligament tears (2) and patellofemoral pain syndrome (60). If a subject has reduced ankle dorsiflexion, they may face their toes outward, which leads to greater subtalar joint pronation but allows them to achieve adequate dorsiflexion to complete the squatting motion (15). This can consequentially lead to greater loading on the body, which may predispose to injury. Regarding the hip joint, reduced hip flexion range of motion in the squat could highlight mobility or stability issues of the hip joint (18,22). Trunk forward flexion has been proposed to increase the stress on the lumbar spine and may be due to reduced hip mobility (33).Poor balance can reduce an individual's ability to maintain a stable base during the movement, which may consequentially reduce performance of functional movements (10) and increase injury risk (30). An overall impression rating of the overhead squat and SLS was also included, with a scoring system of poor (1), average (2), and excellent (3). Reliability analysis was completed by 3 testers on a convenience sample of 15 physically active male college students (19.5 ± 0.6 years, 1.80 ± 5.99 m, 75.67 ± 13.28 kg). Testers underwent 2 familiarization sessions and practiced on 10 subjects, with feedback on the test instruction and scores provided by the lead author. Two sessions were completed a week apart at the same time. Using the ICC, excellent intertester and intratester reliability was found for both the squat and SLS (Table 2).

Subjects

Male adolescent (mean ± *SD*: $n = 292$, age = 15.7 ± 0.7 years, height = 1.76 ± 0.08 m, and body mass = 67.5 ± 10.0 kg) and collegiate ($n = 342$, age = 19.4 ± 1.9 years, height = 1.8 ± 0.07 m, and body mass = 77.6 ± 9.3 kg) Gaelic footballers and hurlers were recruited from 6 schools and 2 collegiate institutions. Eight subjects were injured when they presented at the preseason screening and so were excluded from the study. The study was approved by Dublin City University research ethics committee; all adult subjects provided written informed consent, and minors provided written consent and parental informed consent.

Procedures

Subjects were required to attend a preseason screening wearing shorts and a t-shirt, and all testing was completed barefoot. Tests were completed in a station format with subjects rotating between the 3 stations. At each station, the tester read the test instructions to the subject and demonstrated the test. Squatting technique was assessed using the overhead squat (Figure 1) and SLS (Figure 2). For the overhead squat, subjects were required to stand with their feet shoulder-width distance apart and toes facing forward. They grasped a dowel in both hands and placed it horizontally on top of their head, so their shoulders and elbows were at approximately 90°. They assumed the starting position by straightening their elbows with the dowel overhead. Maintaining an upright torso, the subject was asked to slowly squat down as far as was comfortable while keeping their heels on the floor. They held this position for a count of 1 and returned to the starting position. Three trials were completed, and the scoring system as described previously was completed.

Table 1
Squatting technique scoring system.

Component of the squat	Rating	Scoring definition
Knee to toe alignment	No issue (0)	Patella directly above or behind toes
	Slight issue (1)	Patella beyond toes
	Moderate issue (2)	Medial or lateral epicondyle beyond toes
	Severe issue (3)	Popliteal crease above or beyond toes
Knee medial alignment/knee valgus	No issue (0)	Patella over center of the ankle
	Slight issue (1)	Patella over the medial malleolus
	Moderate issue (2)	Patella beyond the medial malleolus
	Severe issue (3)	Lateral epicondyle medial to the medial malleolus
Toe-out	No issue (0)	Patella aligned lateral to the hallux
	Slight issue (1)	Patella aligned directly over the hallux
	Moderate issue (2)	Patella aligned medial to the hallux
	Severe issue (3)	Lateral epicondyle medial to the hallux
Squat depth	No issue (0)	Thigh below horizontal (parallel to the ground)
	Slight issue (1)	Thigh reaching horizontal
	Moderate issue (2)	Thigh reaching between 45° and horizontal
	Severe issue (3)	Thigh unable to reach 45° from horizontal
Trunk flexion	No issue (0)	Trunk parallel to the tibia
	Slight issue (1)	Small amount of flexion of the trunk beyond parallel with the tibia
	Moderate issue (2)	Large amount of flexion of the trunk beyond parallel with the tibia
	Severe issue (3)	Trunk parallel to the ground (or beyond)
Balance	No issue (0)	Subject steady and not at risk of losing their balance during the squat
	Slight issue (1)	Subject slightly unsteady at certain points during the squat but it does not negatively impact the performance of the squat
	Moderate issue (2)	Subject moderately unsteady during the squat and may or may not negatively impact the performance of the squat
	Severe issue (3)	Subject excessively unsteady during the squat and negatively impacts the performance of the squat.

Table 2
Intertester and intratester reliability of the squat and single-leg squat.*

	Intertester	Intratester
	ICC	ICC
Squat		
Overall impression	1.00	0.98
Knee to toe alignment	0.93	0.85–0.96
Knee valgus	1	1
Toe-out	0.96	0.926
Depth	0.85	0.90–0.96
Trunk flexion	0.94	0.86–0.94
Balance	1	1
Single-leg squat		
Overall impression	0.98	0.97–1.00
Knee to toe alignment	0.94	0.95
Knee valgus	0.95	0.82–0.88
Toe-out	0.92	0.76–0.83
Depth	0.95	0.79–0.92
Trunk flexion	0.87	0.95–1.00
Balance	0.92	0.85–1.00

*ICC = intraclass correlation coefficient.

The SLS was completed on their dominant leg, which was defined as their preferred kicking leg (43). Subjects stood on their dominant leg on the edge of a step with their contralateral hip flexed and leg outstretched in front. The subjects outstretched their arms to 90° with elbows straight and their hands clasped together. Subjects were required to squat down as far as was comfortable and return to the starting position. Three trials were completed, and the same scoring system as the overhead squat was used.

The alternative core stability push-up test as described by O'Connor et al. (46) was used to examine core stability (Figure 3). Subjects were required to complete a press-up while lifting their body as a unit with a straight line between the shoulders, hip, and knees. Subjects began with their feet together, hands shoulder-width apart with their hands and forehead at the level of the athletic tape, which was placed in a straight line on the floor. The test was deemed successful if they could complete the press-up with no lagging or twisting of the spine or hips. Those who completed the test successfully in this position were asked to repeat it again with their right leg lifted 3 cm off the ground. If unsuccessful, they received a good score (3), and if successful, they were given a score of excellent (4). Those who could not complete the first push-up sufficiently completed it again with their chin at the level of athletic tape; if successful, they receive a rating of average (2), and if unable to complete it, they receive a poor score (1).

Injury Assessments. Any injury sustained during training or competition that resulted in restricted performance or time lost from play was examined and recorded on a standardized injury report form over the course of the season (45,47). Injury examinations were completed by a certified athletic therapist alongside third- and fourth-year undergraduate athletic therapy and training students at least weekly. Students were completing their undergraduate placement with the teams involved in the study and were required to attend all training sessions and matches. All students had passed all required classes relating to the diagnosis of musculoskeletal injuries in sport and had undertaken at least 1 year of placement with sports teams before this study. The primary author reviewed all injury diagnoses and standardized injury-report forms on a weekly basis, and for those where the author was not present during the injury examination and queries were present on the diagnosis, a reassessment by the primary author was completed. Lower-extremity injuries were defined as any injury that occurred from the hip to the toe. Trunk injuries incorporated any injury of the spine, abdomen, or thorax.

Statistical Analyses

All statistical analyses were performed using SPSS for Windows version 23. Normative data were presented by calculating the percentage of subjects who were given each rating on the alternative core stability push-up test, overhead squat, and SLS. A single summated overall impression score (a summative score of the alternative core stability push-up test, overhead squat, and SLS) was calculated for all subjects. The maximum score achievable was 10 if an excellent score was provided in all 3 screening tests. Univariate logistic regression was completed to examine whether this single summative score itself could predict lower-extremity injuries, trunk injuries, and whole-body injuries. Receiver operating characteristic (ROC) curves were also implemented to examine whether an optimal cutoff point existed that could identify those at risk of sustaining a lower-extremity injury, trunk injury, and whole-body injury. An area under the curve (AUC) value of greater than 0.6 was set by authors to generate a cutoff point with adequate overall sensitivity and specificity, as a value of 0.5 equals chance (65).

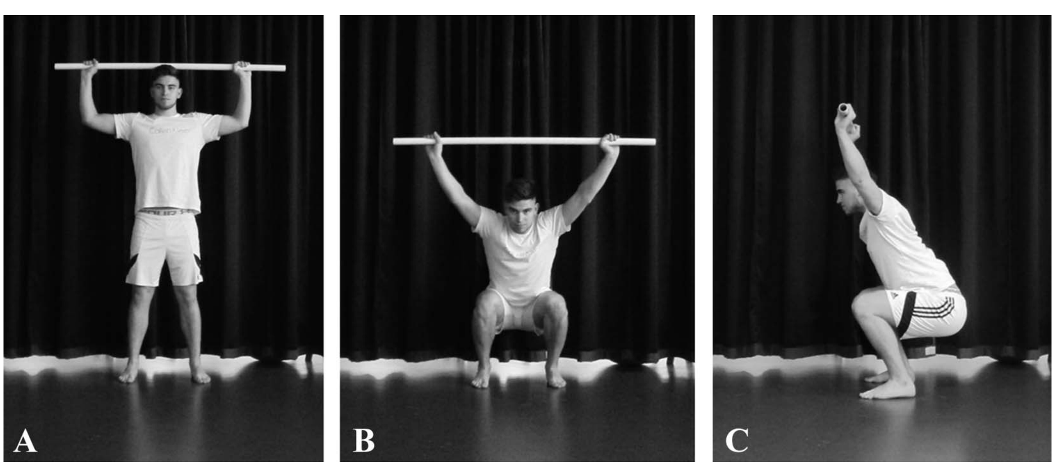

Figure 1. Overhead squat (A) starting position, and (B and C) final squat position.

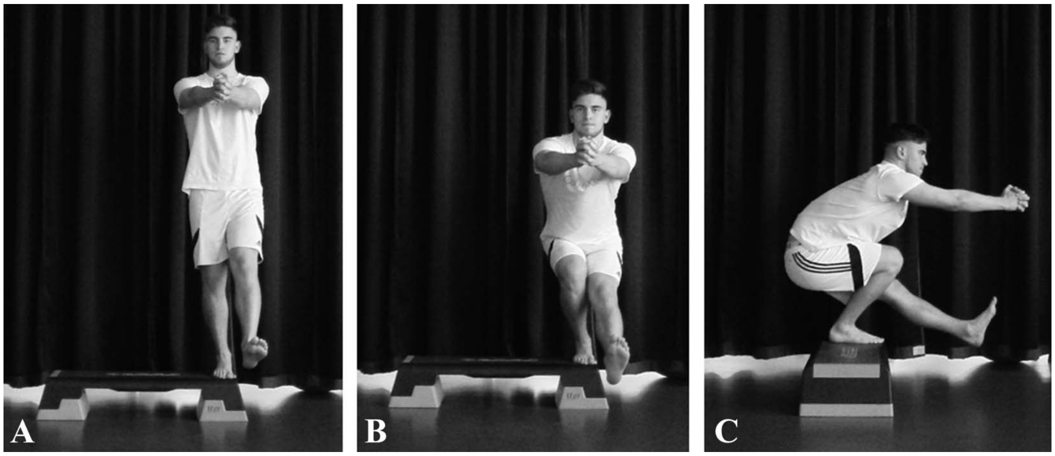

Figure 2. Single-leg squat (A) starting position, and (B and C) final single-leg squat position.

A 2-stage analysis was conducted to examine the predictive ability of the overall impression and segmental criteria scores for the overhead squat, SLS, and alternative core stability pushup test for lower-extremity injuries, trunk injuries, and whole-body injuries. The first step was the univariate regression analysis. Any variables with a p value of $\leq$0.20 on the Wald test in the univariate analysis were then entered into the multivariate analysis (57). No variables displayed multicollinearity as each variable had a tolerance value of greater than 0.10 and a variance inflation factor of less than 10. A separate backward stepwise logistic regression was then completed for lower-extremity injuries, trunk injuries, and whole-body injuries. A $p < 0.10$ was used as a cutoff level for elimination of nonsignificant predictors at each step. Statistical significance of the model was set at an alpha level of 0.5. The overall sensitivity and specificity of the model were also examined along with the OR and 95% CIs of each individual variable in the model.

To examine the strength of the relationship between the 3 screening tests, Spearman's rho correlations were completed using classifications according to Cohen (16) (weak = 0.10–0.29, moderate = 0.30–0.49, and large = 0.50–1.0). The relationship between (a) overall impression scores of the overhead squat and SLS, (b) segmental criteria scores for the overhead squat and SLS with the overall impression score, and (c) the alternative core stability push-up score, segmental criteria scores, and overall impression scores for the overhead squat and SLS were also examined.

Results

Normative Data

Normative data for scores in the alternative core stability push-up test, overhead squat, and SLS are presented in Table 3. A higher percentage of collegiate players received an excellent score (61.8%) in the alternative core stability push-up test than adolescent players (33.7%). Players primarily received a good rating for overall impression of the overhead squat (46.4%) and SLS (47.6%); however, collegiate players performed worse in the SLS than the overhead squat with 51.4% receiving a poor rating. For the segmental scoring in the overhead squat, players predominantly presented with some issues for excessive trunk flexion (72.0%) and squat depth (60.4%). For the SLS, 81.8, 76.7, 71.9, 68.8, and 56.2% presented with issues for excessive trunk flexion, knee to toe alignment, squat depth, knee valgus, and poor balance, respectively.

Injury Prediction

Three hundred eighteen injuries occurred over the course of the season, with 223 of these to the lower-extremity and 32 to the trunk. The single summated score of the overall impression scores of the overhead squat, SLS, and alternative core stability push-up test (of a score of 10) was unable to significantly predict lower-extremity injury or trunk injuries ($p > 0.05$). In fact, performing better in the single summated score of all 3 tests actually significantly increased the likelihood of sustaining a whole-body injury (OR = 1.12 [1.001–1.25], $p = 0.03$). However the sensitivity was 0% and had the same accuracy as the null hypothesis. In addition, ROC curves generated an AUC value of less than 0.6, indicating it was not possible to identify a cutoff point with adequate sensitivity and specificity to predict a player at risk of sustaining a lower-extremity injury, trunk injury, or whole-body injury.

After this, univariate regression analyses were completed initially to examine whether the overall and segmental criteria scores


A B

Figure 3. Alternative core stability push-up test (A) starting position, and (B) final position with right foot slightly off the ground.

Table 3
Normative data for the alternative core stability push-up test, overhead squat, and single-leg squat.*

	All				Adolescent				Collegiate			
Alternative core stability push-up	Poor	Average	Good	Excellent	Poor	Average	Good	Excellent	Poor	Average	Good	Excellent
	4.8	12.6	33.5	49.1	7.9	18.9	39.5	33.7	2.3	7.4	28.5	61.8
Overhead squat	Poor	Good	Excellent		Poor	Good	Excellent		Poor	Good	Excellent	
Overall impression	34.3	46.4	19.3		36.9	40.1	23.0		32.2	51.6	16.2	
Issue	None	Minor	Moderate	Severe	None	Minor	Moderate	Severe	None	Minor	Moderate	Severe
Knee to toe	60.1	23.4	12.1	4.4	68.5	14.9	9.3	7.3	53.3	30.3	14.4	2.0
Knee valgus	74.3	15.0	8.4	2.3	67.5	18.7	9.0	4.8	79.9	11.9	7.9	0.3
Toe-out	60.0	25.9	10.7	3.4	60.2	22.8	12.1	4,8	59.8	28.3	9.6	2.3
Depth	39.5	29.6	24.6	6.2	39.2	32.3	23.6	4.9	39.7	27.5	25.5	7.4
Trunk flexion	27.9	32.1	26.5	13.4	23.3	39.9	24.3	12.5	31.7	25.8	28.3	14.2
Balance	68.3	24.0	7.0	0.6	62.8	27.8	9.4	0.0	72.8	21.0	5.1	1.1
Single-leg squat	Poor	Good	Excellent		Poor	Good	Excellent		Poor	Good	Excellent	
Overall impression	44.1	47.6	8.4		35.2	51.9	12.9		51.4	43.9	4.6	
Issue	None	Minor	Moderate	Severe	None	Minor	Moderate	Severe	None	Minor	Moderate	Severe
Knee to toe	23.4	51.6	22.4	2.7	25.3	55.6	17.0	2.1	21.7	48.3	26.9	3.1
Knee valgus	31.2	42.2	19.9	6.7	27.8	49.0	18.1	5.2	34.0	36.6	21.4	8.0
Toe-out	87.5	9.9	2.4	0.3	87.5	9.0	3.1	0.3	87.4	10.6	1.7	0.3
Depth	28.1	29.9	36.8	5.2	26.7	37.8	30.2	5.2	29.1	23.4	42.3	5.1
Trunk flexion	18.2	44.2	27.3	10.3	11.1	60.1	21.9	6.9	24.0	31.1	31.7	13.1
Balance	43.7	28.5	23.8	3.9	59.0	21.2	14.2	5.6	31.1	34.6	31.7	2.6

*Knee to toe; knee to toe alignment.

of the overhead squat, SLS, and alternative core stability push-up test could predict lower-extremity injuries, trunk injuries, and whole-body injuries. The p value, OR, and 95% CI of this univariate analysis are displayed in Table 4. A poor score on the alternative core stability push-up test doubled the odds of sustaining a whole-body injury during the season (OR = 2.00 [1.26–3.17]). Although poor performance in the overall impression of the overhead squat did increase the odds of sustaining an injury (OR = 1.30 [0.92–1.83]), it was not statistically significant, and this was also not the case for the SLS (OR = 0.86 [0.62–1.19]).

The variables with a p value ≤ 0.20 were included in the multivariate regression analysis, and all multivariate regression analyses were adjusted for age. A backward stepwise logistic regression created a statistically significant model to predict whole-body injuries in Gaelic games ($\chi^2 = 59.60$, $p < 0.0001$), with the individual predictors left in the model displayed in Table 5. The model had a sensitivity of 40.2% and specificity of 80.6% and, as a whole, explained between 8.4 and 11.6% of the variance in injury status and correctly classified 65.9% of cases.

A significant model was noted for lower-extremity injuries ($\chi^2 = 49.53$, $p < 0.0001$) with a sensitivity and specificity of 44.2 and 76.5%, respectively. The model explained 7.7–10.6% of the variance in injury status and correctly classified 64.8% of cases. The individual predictors left in this model are presented in Table 5.

Table 4
Univariate regression analysis for whole-body injuries, lower-extremity injuries, and trunk injuries.*

	Whole-body injury			Lower-extremity injury			Trunk injury		
	p	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***	**OR**	**95% CI**
Overhead squat									
Overall impression	0.14†	1.30	0.92–1.83	0.49	1.14	0.78–1.67	0.60	1.25	0.54–2.91
Knee to toe	0.004†	1.63	1.16–2.28	0.06†	1.42	0.98–2.06	0.93	0.96	0.44–2.11
Knee valgus	<0.0001†	2.71	1.79–4.10	<0.0001†	2.64	1.63–4.28	0.09†	2.86	0.85–9.63
Toe-out	0.01†	1.56	1.11–2.17	0.12†	1.34	0.93–1.93	0.38	0.71	0.33–1.53
Depth	0.04†	0.71	0.51–1.00	0.92	0.98	0.68–1.41	0.07†	0.43	0.17–1.07
Trunk flexion	0.07†	0.71	0.49–1.03	0.01†	0.56	0.36–0.86	0.28	1.55	0.70–3.45
Balance	<0.0001†	2.26	1.56–3.27	<0.0001†	2.14	1.41–3.27	0.29	1.65	0.66–4.16
Single-leg squat									
Overall impression	0.35	0.86	0.62–1.19	0.31	0.83	0.58–1.19	0.41	0.72	0.33–1.56
Knee to toe	0.07†	1.41	0.97–2.05	0.03†	1.58	1.06–2.35	0.89	0.94	0.37–2.36
Knee valgus	0.03†	1.45	1.03–2.05	0.10†	1.37	0.95–2.00	0.81	1.11	0.49–2.51
Toe-out	0.003†	2.36	1.34–4.14	0.04†	1.93	1.04–3.60	0.42	1.83	0.43–7.88
Depth	0.02†	0.65	0.45–0.94	0.14†	0.74	0.49–1.11	0.27	0.57	0.21–1.53
Trunk flexion	0.17†	1.33	0.88–2.01	0.35	1.24	0.79–1.93	0.96	1.02	0.38–2.76
Balance	0.12†	0.77	0.56–1.07	0.20	0.79	0.55–1.13	0.48	0.75	0.34–1.66
Alternative core stability push-up	0.003†	2.00	1.26–3.17	0.03†	1.78	1.07–2.96	0.22	2.50	0.58–10.74

*OR = odds ration; CI = confidence interval.
†p value $\leq$ 0.20.

the Journal of Strength and Conditioning Research™

Table 5

Multivariate regression analyses: individual predictors remaining in whole-body injury, lower-extremity injury, and trunk injury models.*

Predictor	OR	95% CI
Whole-body injury		
Overhead squat		
Knee valgus	2.39	1.53–3.72
Depth	0.67	0.46–0.96
Balance	1.87	1.26–2.77
Single-leg squat		
Knee valgus	1.55	1.06–2.25
Toe-out	2.04	1.13–3.69
Balance	0.65	0.46–0.94
Lower-extremity injury		
Overhead squat		
Knee valgus	2.59	1.66–4.02
Balance	1.72	1.16–2.54
Trunk flexion	0.66	0.45–0.97
Single-leg squat		
Toe-out	1.98	1.10–3.56
Alternative core stability push-up	1.52	0.92–2.51
Trunk injury		
Overhead squat		
Knee valgus	2.88	0.86–9.72
Depth	2.36	0.94–5.94

*OR = odds ration; CI = confidence interval.

A statistically significant model was found with the 2 predictors inputted ($\chi^2 = 7.60, p = 0.02$) for trunk injury. However, a sensitivity of 0% and specificity of 100% was noted and explained just 1.2–4.0% of the variance in injury status. The model correctly classified 95.8% of cases. Knee valgus during the overhead squat and insufficient depth when completing the overhead squat increased their odds of a trunk injury by 2.88 and 2.36, respectively (Table 5).

Relationships Between the Tests

The overall impression scores of the overhead squat and SLS were significantly moderately correlated ($r = 0.31, p < 0.0001$). The alternative core stability push-up test was significantly weakly correlated with both the overhead squat ($r = 0.26, p < 0.0001$) and SLS ($r = 0.16, p < 0.0001$) overall impression scores.

Table 6 details the correlation between each individual segmental criterion and the overall impression score for the overhead squat and the SLS. All correlations were negative, indicating the higher overall impression score was related to a lesser segmental issue score. For the overhead squat, a significant large relationship was found for squat depth with moderate relationships noted for trunk flexion and balance. For the SLS, a significant large relationship was found for balance with moderate relationships noted for squat depth, trunk flexion, and knee valgus.

The alternative core stability push-up test was not statistically significantly related to any segmental criteria in the SLS, aside from a weak negative relationship for toe-out ($r = -0.15, p < 0.0001$). Table 7 displays the relationship between the alternative core stability push-up test and the overhead squat segmental criteria, whereby only weak relationships were noted.

Discussion

This study aimed to examine the ability of 3 simple, field-based screening tests (the overhead squat, SLS, and alternative core stability push-up test) to predict lower-extremity injuries, trunk injuries, and whole-body injuries in Gaelic game players. The single summated score of all 3 screening tests was unable to significantly predict lower-extremity or trunk injuries. Although the scoring system did reach statistical significance for whole-body injuries ($p = 0.03$), the sensitivity was zero and it did not accurately predict whole-body injuries better than the null hypothesis. In addition, no cutoff point with adequate sensitivity or specificity was able to be generated using this single summated score. Thus, the use of an overall summated numeric scoring system only as a method of identifying players at risk of sustaining an injury during the season is not advised. In addition, although summated numeric scoring systems (for example, the FMS) may be easier and less time-consuming to use by strength and conditioning coaches and clinicians, the numeric output does not provide adequate contextual information to prescribe exercises to reduce injury risk. When incorporating a combined overall impression and segmental criteria scoring, a significant model to predict whole-body injuries ($p < 0.0001$), lower-extremity injuries ($p < 0.0001$), and trunk injuries ($p = 0.02$) was generated. This indicates the inclusion of segmental criteria scoring improves the ability to identify a player potentially at risk of injury. However, the sensitivity of the models that predicted whole-body injuries and lower-extremity injuries was low and correctly classified as only 65.9 and 64.8% of cases. Although the current study only examined Gaelic games players, the findings may be applicable to other field sports, given the commonality in the demands of the sports and injuries that occur. Similar to the current study's findings, a recent systematic review reported that there is inconsistent evidence in current research, examining sport or occupational populations, that an overall score of poor movement quality is related to increased risk of sustaining a lower-extremity injury (61). In soccer players, the single summative score of all FMS tests did not statistically significantly predict noncontact injury, but the overall impression scores of the overhead squat and trunk stability tests only did predict noncontact injury (51). In firefighters, the overhead squat (OR = 1.21) and trunk stability test (OR = 1.30) were also predictive of whole-body injuries (11). However, segmental criteria scoring of the overhead squat were not analyzed in these studies. By contrast, a prospective study completed over 2 years reported that the overhead squat, SLS, and trunk stability test were not significantly correlated to injury in basketball players (40). However, only 14 players from 1 team were included in the study compared with the 627 across multiple teams in the current study. Although the model incorporating the combined overall and segmental criteria scoring system predicting trunk injuries did reach statistical significance in our study, it explained very little injury variance and did not perform and predict injured cases much better than chance. This may be due to the low number of trunk injuries sustained in our study ($n = 32$) relative to the lower-extremity ($n = 223$) and whole-body ($n = 318$) injuries.

A total of 55.7% of Gaelic players presented with a knee valgus motion during the overhead squat compared with 68.8% during the SLS, with players predominantly receiving a minor issue rating (42.2%). Knee valgus demonstrated in the overhead squat increased the odds of sustaining a whole-body injury (OR = 2.39 [1.53–3.72]), lower-extremity injury (OR = 2.59 [1.66–4.02]), and trunk injury (OR = 2.88 [0.86–9.72]). In addition, knee valgus in the SLS was found to increase the likelihood of receiving a whole-body injury by 1.55. Research has shown that those demonstrating knee valgus during the SLS have weaker hip abduction, knee flexion, and knee extension peak torque (14). Knee

Table 6
Relationship between segmental criteria scores and overall impression ratings in squatting techniques.

	Overhead squat overall impression			Single-leg squat overall impression		
	p	*r*		*p*	*r*	
Knee to toe	<0.0001*	−0.27	Weak	<0.0001*	−0.23	Weak
Knee valgus	<0.0001*	−0.20	Weak	<0.0001*	−0.37	Moderate
Toe-out	<0.0001*	−0.19	Weak	0.002*	−0.12	Small
Depth	<0.0001*	−0.51	Large	<0.0001*	−0.44	Moderate
Trunk flexion	<0.0001*	−0.46	Moderate	<0.0001*	−0.41	Moderate
Balance	<0.0001*	−0.32	Moderate	<0.0001*	−0.53	Large

*indicates $p < 0.05$.

valgus also only influenced the overall impression rating for the SLS, with a moderate correlation observed. This was also reported by Weeks et al. (60) who found that knee mediolateral displacement significantly predicted SLS performance. Therefore, any Gaelic players who present with knee valgus during screening should undertake preventative exercise programs including hip abductor, hamstring, and quadriceps muscle-strengthening exercises (14) and technique correction activities to avoid this at-risk position (52).

Issues with squat depth were noted in both the overhead squat and SLS, with up to a third and two-fifths of subjects demonstrating moderate and severe issues, respectively. However, reduced depth of the squat did not predict whole-body or lower-extremity injuries and so may not be a useful inclusion in the segmental scoring of the squat. In the multivariate model, reduced depth of the overhead squat was found to be predictive of trunk injuries (OR = 2.36), but this was not significant (95% CI: 0.94–5.94). Reduced depth during squatting is proposed to be due to reduced hip mobility and stability (18). Kim et al. (33) reported that reduced hip flexion and internal rotation at the hip was significantly negatively correlated with squat depth, and reduced hip flexion mobility was found to significantly predict squat depth. In addition, although greater hip mobility was associated with significantly better performance in basketball players, no relationship with injury was noted, similar to the current study (40). Trunk flexion may have both positive and negative implications. Trunk flexion can be a compensatory movement due to poor hip mobility and has been proposed to increase the stress placed on the lumbar spine (33). In our study, however, although excessive trunk flexion during the overhead squat was found to be common (72%), it was actually found to be protective of sustaining a lower-extremity injury (OR = 0.66 [0.45–0.97]). In fact, more trunk flexion can act to cushion the load during landing and stabilize the knee (6,54), a common site of injury in Gaelic games (45,47).

Toe-out during the SLS was found to double the odds of sustaining a whole-body injury and lower-extremity injury, with 12.6% of subjects presenting with this compensatory pattern during the SLS. Toe-out during the SLS may be a compensation strategy by subjects with limited dorsiflexion, by allowing increased subtalar joint pronation (15). During the contact phase of gait, subtalar joint pronation is coupled with internal tibial internal rotation. For those who overpronate, the tibia remains in an internally rotated position for an extended period, transmitting abnormal forces upward in the kinetic chain, which can increase injury risk (3). Reduced dorsiflexion can occur because of tight calf musculature and previous ankle injuries. Therefore, stretching and mobilizations of the talocrural joint may be prescribed to those presenting with this compensatory pattern (29). Poor balance noted on the overhead squat was found to significantly increase the odds of receiving a whole-body injury and lower-extremity injury by 1.87 and 1.72, respectively. Interestingly, this relationship was not observed during the SLS. Ankle injuries are frequent in Gaelic games, accounting for 10–12% of all injuries in adolescent and collegiate Gaelic games (45,47), and poor lower limb proprioception has been previously identified as a risk factor for injury in adult Gaelic footballers (59).

Players predominantly performed well in the alternative core stability push-up test with 82.6% of them receiving either a good or an excellent rating, which is higher than reported in male runners (43.5%) (1) and young active male and female adults (76.2%) (53) who received a score of 3 in the trunk stability test. Collegiate players (61.8%) received a higher amount of excellent scores than adolescent players (33.7%), indicating that core stability improved as players aged. High school female cheerleaders also demonstrated poorer core stability than cheerleaders with a mean age of 21 (36), similar to the current study's collegiate mean age. A low percentage of adolescent (7.9%) and collegiate (2.3%) players was rated poorly on the alternative core stability push-up test. When adjusted for age, poor scores in the alternative core stability push-up test increased the odds of sustaining a lower-extremity injury by 1.52. Therefore, although core stability does not seem to be a common issue with Gaelic players, those who sustain a poor rating in the alternative core stability push-up test are at an increased risk of sustaining a lower-extremity injury.

The sensitivity of a model indicates its ability to accurately identify those who are at risk of sustaining an injury (true positive rate), whereas, in contrast, the specificity indicates the ability to accurately identify those who are not at risk of sustaining an injury (true negative rate) (49). For the whole-body injury and lower-extremity injury models, the specificity was found to be high (80.6 and 76.5%), but the sensitivity was low (40.2 and 44.2%, respectively). Thus, these 3 low-cost and easy-to-implement visual assessment screening tests used in this study

Table 7
Relationship between overhead squat segmental criteria and the overall impression rating for the alternative core stability push-up test.

	Alternative core stability push-up		
Overhead squat	*p*	*r*	
Knee to toe	<0.0001*	−0.14	Weak
Knee valgus	<0.0001*	−0.21	Weak
Toe-out	0.002*	−0.13	Weak
Depth	0.74	−0.01	Weak
Trunk flexion	0.28	−0.04	Weak
Balance	<0.0001*	−0.22	Weak

*indicates $p < 0.05$.

may have a role as a preliminary screening method to identify those who are not at a high risk of sustaining injury (i.e., those who are not identified as at risk), with others referred on for a more detailed and comprehensive screening assessment.

To improve the sensitivity of the overhead squat and SLS, future research could consider adapting them in a number of ways including increasing the speed of the tests, incorporating additional loading (5), completing the screening tests when fatigued, or the addition of reactionary sport-specific element such as catching a ball when completing the SLS. Adapting screening tests can potentially highlight individuals with movement issues (5), as observed by Frost et al. in firefighters performing a squat with greater load and speed (23).

A secondary aim of our study was to report the normative data for this population. Normative data are important because these provide a standardized reference of results, allowing for strength and conditioning coaches and clinicians to compare their results with a comparable population (19). Players predominantly received a good rating for the overall impression of the overhead squat; however, just over half and a third of collegiate and adolescent players, respectively, performed poorly in the SLS. Schneider et al. (53) published normative data for the overhead squat assessed using the FMS grading system and found a lower percentage of young active men received a poor rating (15%) than those in the current study (34.3%). In addition, both Schneiders et al. (53) (61%) and Agresta et al. (1) (78.3%) reported a higher percentage of male runners receiving an average score than those in this study (46.4%). This may reflect lower muscular strength and neuromuscular control. Alternatively, the inclusion of segmental criteria scoring in the current study may have led the tester to more critically appraise the overall squatting technique than other strategies that require a summative score only.

A third aim of the study was to examine the relationship between all 3 screening tests to determine whether all 3 are required to be used during a preseason screening. Although a significant relationship was noted between all 3 of the tests, the relationship between the overhead squat and SLS was only moderate, and the relationships between the alternative core stability push-up test and the overhead squat and SLS were weak. The weak correlation between the alternative core stability push-up test and the SLS is surprising, as previous research has found significant relationships between other isometric core endurance tests and the SLS in healthy adults (48). Thus, either core stability does not impact lower limb function substantially in the SLS. Alternatively, it may suggest the alternative core stability push-up test is not a valid measure of core stability. Further research on the validity of the alternative core stability push-up test is required. All 3 tests contributed to the lower-extremity injury prediction model. Thus, these 3 screening tests in general examine different elements of movement functioning, and substituting 1 test for another would not be of benefit. However, their usefulness is primarily as a preliminary screening method. Future research should consider examining other screening tests with higher sensitivity.

Squat depth exhibited the strongest correlation with the overall impression score for the overhead squat, and a moderate correlation was noted for the SLS. This is similar to Weeks et al. (60), whereby peak knee flexion was the strongest predictor of SLS performance, which explained 33–36% of the overall performance rating. These findings highlight the importance of ensuring adequate mobility of the hip and knee joint to facilitate full range of motion and squat depth. In addition, poor balance was found to be correlated with a poorer overall impression score in the SLS, indicating that improving balance may be related to enhancing SLS performance. None of the segmental criteria of the overhead squat and SLS were significantly correlated with the alternative core stability push-up test, except for toe-out; however, only a weak relationship was noted. This finding, combined with the weak overall relationship between the overhead squat, SLS, and the alternative core stability push-up test, indicates that although weak core stability has been purported as a potential reason for poor performance in squatting technique (18), it may at best have a small role in the performance of the overhead squat and SLS. Instead, strength and conditioning coaches and clinicians should focus on improving gluteal, quadriceps, and hamstring strength, mobility, and balance because they may have a greater influence on squatting technique.

This study examined the predictive ability of these screening tests in male Gaelic players only; therefore, the generalizability of these findings to female players or other sports should be completed with caution.

Practical Applications

The overhead squat, SLS, and alternative core stability push-up tests described in this study are simple, time efficient, and functional visual measures of squatting technique and core stability that are easy to implement by strength and conditioning coaches and clinicians. The combined overall impression and segmental criteria scoring system can be used as a screening tool. However, it should only be used as a preliminary screening method, and those identified as potentially at risk of injury should undertake a more comprehensive and detailed assessment.

Acknowledgments

This research was supported by professional development funding by the Athlone Institute of Technology and the Irish Research Council for Science, Engineering and Technology (IRCSET) "Embark Initiative" grant.

References

1. Agresta C, Slobodinsky M, Tucker C. Functional movement screen TM-normative values in healthy distance runners. *Int J Sports Med* 35: 1203–1207, 2014.
2. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: A review of prevention programs aimed to modify risk factors and to reduce injury rates. *Knee Surg Sports Traumatol Arthrosc* 17: 859–879, 2009.
3. Beckett ME, Massie DL, Bowers KD, Stoll DA. Incidence of hyperpronation in the ACL injured knee: A clinical perspective. *J Athl Train* 27: 58–62, 1992.
4. Bishop C, Brierly S, Turner AN. The single leg squat: When to prescribe this exercise. *Prof Strength Cond J* 41: 17–26, 2016.
5. Bishop C, Villiere A, Turner AN. Addressing movement patterns by using the overhead squat. *Prof Strength Cond J* 40: 7–12, 2016.
6. Blackburn JT, Padua DA. Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clin Biomech* 23: 313–319, 2008.
7. Blake C, O'Malley E, Gissane C, Murphy JC. Epidemiology of injuries in hurling: A prospective study 2007–2011. *BMJ Open* 4: e005059, 2014.
8. Bliven KCH, Anderson BE. Core stability training for injury prevention. *Sports Health* 5: 514–522, 2013.
9. Bonazza NA, Smuin D, Onks CA, Silvis ML, Dhawan A. Reliability, validity, and injury predictive value of the functional movement screen: A

systematic review and meta-analysis. *Am J Sports Med* 45: 725–732, 2017.
10. Bressel E, Yonker JC, Kras J, Heath EM. Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *J Athl Train* 42: 42–46, 2007.
11. Butler RJ, Contreras M, Burton LC, Plisky PJ, Goode A, Kiesel K. Modifiable risk factors predict injuries in firefighters during training academies. *Work* 46: 11–17, 2013.
12. Butler RJ, Plisky PJ, Southers C, Scoma C, Kiesel KB. Biomechanical analysis of the different classifications of the Functional Movement Screen deep squat test. *Sports Biomech* 9: 270–279, 2010.
13. Chorba RS, Chorba DJ, Bouillon LE, Overmyer CA, Landis JA. Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *N Am J Sports Phys Ther* 5: 47–54, 2010.
14. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM. Relationship between hip and knee strength and knee valgus during a single leg squat. *J Appl Biomech* 22: 41–50, 2006.
15. Clark M, Lucett S. Corrective Strategies for Foot and Ankle Impairments. In: *National Academy of Sports Medicine. NASM Essentials of Corrective Exercise Training*. Philadelphia, PA: Lippincott Williams & Wilkins, 2010. pp. 273–277.
16. Cohen J. The Significance of a Product Moment. In: *Statistical Power Analysis for the Behavioral Sciences*. New Jersey: Routledge, 1988. pp. 79–81.
17. Cook G, Burton L, Hoogenboom B. Pre-participation screening: The use of fundamental movements as an assessment of function—Part 1. *N Am J Sports Phys Ther* 1: 62–72, 2006.
18. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: The use of fundamental movements as an assessment of function—Part 1. *Int J Sports Phys Ther* 9: 396–409, 2014.
19. Corkery M, Briscoe H, Ciccone N, et al. Establishing normal values for lower extremity muscle length in college-age students. *Phys Ther Sport* 8: 66–74, 2007.
20. Cullen BD, Roantree MT, McCarren AL, et al. Physiological profile and activity pattern of minor gaelic football players. *J Strength Cond Res* 31: 1811–1820, 2017.
21. Dorrel BS, Long T, Shaffer S, Myer GD. Evaluation of the functional movement screen as an injury prediction tool among active adult populations: A systematic review and meta-analysis. *Sports Health* 7: 532–537, 2015.
22. Frohm A, Heijne A, Kowalski J, Svensson P, Myklebust G. A nine-test screening battery for athletes: A reliability study. *Scan J Med Sci Sports* 22: 306–315, 2012.
23. Frost DM, Beach TAC, Callaghan JP, McGill SM. The influence of load and speed on individuals' movement behavior. *J Strength Cond Res* 29: 2417–2425, 2015.
24. Fry AC, Smith JC, Schilling BK. Effect of knee position on hip and knee torques during the barbell squat. *J Strength Cond Res* 17: 629–633, 2003.
25. Gabbe BJ, Bennell KL, Wajswelner H, Finch CF. Reliability of common lower extremity musculoskeletal screening tests. *Phys Ther Sport* 5: 90–97, 2004.
26. Garrick JG. Preparticipation orthopedic screening evaluation. *Clin J Sport Med* 14: 123, 2004.
27. Garrison M, Westrick R, Johnson MR, Benenson J. Association between the functional movement screen and injury development in college athletes. *Int J Sports Phys Ther* 10: 21–28, 2015.
28. Hegedus E, McDonough S, Bleakley C, et al. Physical performance tests predict injury in national collegiate athletic association athletes: A three-season prospective cohort study. *Br J Sports Med* 50: 1333–1337, 2016.
29. Hoch MC, Staton GS, McKeon PO. Dorsiflexion range of motion significantly influences dynamic balance. *J Sci Med Sport* 14: 90–92, 2011.
30. Hrysomallis C. Relationship between balance ability, training and sports injury risk. *Sports Med* 37: 547–556, 2007.
31. Kazman JB, Galecki JM, Lisman P, Deuster PA, O'Connor FG. Factor structure of the functional movement screen in marine officer candidates. *J Strength Cond Res* 28: 672–678, 2014.
32. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason functional movement screen?. *N Am J Sports Phys Ther* 2: 147–158, 2007.
33. Kim SH, Kwon OY, Park KN, Jeon IC, Weon JH. Lower extremity strength and the range of motion in relation to squat depth. *J Hum Kinet* 45: 59–69, 2015.
34. Kivlan BR, Martin RL. Functional performance testing of the hip in athletes: A systematic review for reliability and validity. *Int J Sports Phys Ther* 7: 402–412, 2012.
35. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc* 36: 926–934, 2004.
36. Leitz R. *The Relationship Between Core Stability Related Measures and Performance in Adolescent All-Star Cheerleaders*. 2015. Available at: https://digitalcommons.georgiasouthern.edu/etd/1266. Accessed September 8, 2017.
37. Maffey L, Emery C. Physiotherapist delivered preparticipation examination: Rationale and evidence. *N Am J Sports Phys Ther* 1: 176–186, 2006.
38. Mauntel TC, Frank BS, Begalle RL, Blackburn JT, Padua DA. Kinematic differences between those with and without medial knee displacement during a single-leg squat. *J Appl Biomech* 30: 707–712, 2014.
39. McCunn R, aus der Fünten K, Fullagar HHK, McKeown I, Meyer T. Reliability and association with injury of movement screens: A critical review. *Sports Med* 46: 763–781, 2016.
40. McGill SM, Andersen JT, Horne AD. Predicting performance and injury resilience from movement quality and fitness scores in a basketball team over 2 years. *J Strength Cond Res* 26: 1731–1739, 2012.
41. McLean SG, Walker K, Ford KR, et al. Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *Br J Sports Med* 39: 355–362, 2005.
42. Minick KI, Kiesel KB, Burton L, Taylor A, Plisky P, Butler RJ. Interrater reliability of the functional movement screen. *J Strength Cond Res* 24: 479–486, 2010.
43. Mokha M, Sprague PA, Gatens DR. Predicting musculoskeletal injury in national collegiate athletic association Division II athletes from asymmetries and individual-test versus composite functional movement screen scores. *J Athl Train* 51: 276–282, 2016.
44. Murphy JC, O'Malley E, Gissane C, Blake C. Incidence of injury in gaelic football: A 4-year prospective study. *Am J Sports Med* 40: 2113–2120, 2012.
45. O'Connor S, McCaffrey N, Whyte EF, Moran KA. Epidemiology of injury in male adolescent Gaelic games. *J Sci Med Sport* 19: 384–388, 2016.
46. O'Connor S, McCaffrey N, Whyte E, Moran K. The development and reliability of a simple field based screening tool to assess core stability in athletes. *Phys Ther Sport* 20: 40–44, 2016.
47. O'Connor S, McCaffrey N, Whyte EF, Moran KA. Epidemiology of injury in male collegiate Gaelic footballers in one season. *Scand J Med Sci Sports* 27: 1136–1142, 2017.
48. Okada T, Huxel K, Nesser T. Relationship between core stability, functional movement and performance. *J Strength Cond Res* 25: 252–261, 2011.
49. Parikh R, Mathai A, Parikh S, Chandra Sekhar G, Thomas R. Understanding and using sensitivity, specificity and predictive values. *Indian J Ophthalmol* 56: 45–50, 2008.
50. Roe M, Blake C, Gissane C, Collins K. Injury scheme claims in gaelic games: A review of 2007–2014. *J Athl Train* 51: 303–308, 2016.
51. Rusling C, Edwards KL, Bhattacharya A, et al. The functional movement screening tool does not predict injury in football. *Prog Ortho Sci* 1: 41–46, 2015.
52. Scase E, Cook J, Makdissi M, Gabbe B, Shuck L. Teaching landing skills in elite junior Australian football: Evaluation of an injury prevention strategy. *Br J Sports Med* 40: 834–838, 2006.
53. Schneiders AG, Davidsson Å, Hörman E, Sullivan SJ. Functional movement screenTM normative values in a young active population. *Int J Sports Phys Ther* 6: 75–82, 2011.
54. Shimokochi Y, Ambegaonkar JP, Meyer EG, Lee SY, Shultz SJ. Changing sagittal plane body position during single-leg landings influences the risk of non-contact anterior cruciate ligament injury. *Knee Surg Sports Traumatol Arthrosc* 21: 888–897, 2013.
55. Tee JC, Klingbiel JFG, Collins R, Lambert MI, Coopoo Y. Preseason functional movement screen component tests predict severe contact injuries in professional rugby union players. *J Strength Cond Res* 30: 3194, 2016.
56. Teyhen DS, Shaffer SW, Lorenson CL, et al. The functional movement screen: A reliability study. *J Orthop Sports Phys Ther* 42: 530–540, 2012.
57. Van Middelkoop M, Kolkman J, Van Ochten J, Bierma-Zeinstra SMA, Koes BW. Risk factors for lower extremity injuries among male marathon runners. *Scan J Med Sci Sports* 18: 691–697, 2008.
58. Warren M, Smith CA, Chimera NJ. Association of the functional movement screen with injuries in Division I athletes. *J Sport Rehab* 24: 163–170, 2015.
59. Watson AWS. Ankle sprains in players of the field-games Gaelic football and hurling. *J Sports Med Phys Fitness* 39: 66–70, 1999.

60. Weeks BK, Carty CP, Horan SA. Kinematic predictors of single-leg squat performance: A comparison of experienced physiotherapists and student physiotherapists. *BMC Musculoskelet Disord* 13: 207, 2012.
61. Whittaker JL, Booysen N, de la Motte S, et al. Predicting sport and occupational lower extremity injury risk through movement quality screening: A systematic review. *Bri J Sports Med* 51: 580–585, 2017.
62. Willson JD, Dougherty CP, Ireland ML, Davis IM. Core stability and its relationship to lower extremity function and injury. *J Am Acad Orthop Surg* 13: 316–325, 2005.
63. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. The effects of core proprioception on knee injury: A prospective biomechanical-epidemiological study. *Am J Sports Med* 35: 368–373, 2007.
64. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: Prospective biomechanical-epidemiologic study. *Am J Sports Med* 35: 1123–1130, 2007.
65. Zou K, O'Malley J, Mauri L. Receiver-operating characteristic analysis for evaluating diagnostic tests and predictive models. *Circulation* 115: 654–657, 2007.