Preseason functional movement screen component tests predict severe contact injuries in professional rugby union players

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Abstract

Rugby union is a collision sport with a relatively high risk of injury. The ability of the Functional Movement Screen (FMS) or its component tests to predict the occurrence of severe (≥28 days) injuries in professional players was assessed. Ninety FMS test observations from 62 players across 4 different time periods were compared with severe injuries sustained during 6 months after FMS testing. Mean composite FMS scores were significantly lower in players who sustained severe injury (injured 13.2 ± 1.5 vs. noninjured 14.5 ± 1.4, Effect Size = 0.83, large) because of differences in in-line lunge (ILL) and active straight leg raise scores (ASLR). Receiver-operated characteristic curves and 2 × 2 contingency tables were used to determine that ASLR (cut-off 2/3) was the injury pre-dictor with the greatest sensitivity (0.96, 95% confidence interval [CI] = 0.79–1.0). Adding the ILL in combination with ASLR (ILL + ASLR) improved the specificity of the injury pre-diction model (ASLR specificity = 0.29, 95% CI = 0.18–0.43 vs. ASLR + ILL specificity = 0.53, 95% CI = 0.39–0.66, $p \leq 0.05$). Further analysis was performed to determine whether FMS tests could predict contact and noncontact injuries. The FMS composite score and various combinations of compo-nent tests (deep squat [DS] + ILL, ILL + ASLR, and DS + ILL + ASLR) were all significant predictors of contact injury. The FMS composite score also predicted noncontact injury, but no component test or combination thereof produced a similar result. These findings indicate that low scores on various FMS component tests are risk factors for injury in professional rugby players.

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Introduction

Rugby union is a full-contact sport defined by repetitive bouts of short-duration, high-intensity work during which players collide, sometimes while running at full speed (9). Despite numerous interventions by World Rugby to make the game safer through law changes (13,17), injuries still occur frequently in rugby union (41). As such, there is a need for the further development of strategies to reduce injuries in this sport. One promising strategy for reducing injuries is the use of preseason screening tools to identify players at greater risk of injury before participation so that corrective strategies can be implemented (28).

A promising screening tool for injury risk in rugby union is the Functional Movement Screen (FMS) (6,7). The FMS purports to be a comprehensive test of mobility and stability in various fundamental movement patterns (6,7). The FMS consists of 7 movement tests; (a) deep squat (DS), (b) hurdle step, (c) in-line lunge (ILL), (d) shoulder mobility (SM), (e) active straight leg raise (ASLR), (f) trunk stability push-up, and (g) rotary stability (RS) tests, and 3 clearing tests for (a) shoulder, (b) spinal extension, and (c) spinal flexion (6,7). Each component test is scored on an ordinal scale from 0 to 3 (0, 1, 2 or 3) based on the quality of the movement pattern exhibited, giving a composite test score out of 21 for all test components. The FMS has good interrater reliability (Intraclass Correlation Coefficient [ICC] = 0.9) (10,37). It has been proposed that poor performance in this type of com-prehensive movement examination may be a risk factor for sports injury (28,33). A recent review of FMS research indi-cated that there was “moderate scientific evidence” to support the use of FMS as a predictor of injury risk (27). Notably, for collision sport athletes, Kiesel et al. showed that an FMS score ≤14 was predictive of serious injury (>21 days) in professional American Football players (25) and that movement asymmetries highlighted by the FMS test increased relative injury risk (23). The link between low FMS scores and injury has also been demonstrated in female collegiate athletes (5) and military (31,32) and general populations (30). In contrast, some studies have shown no association between FMS score and injury risk (26,38). The primary aim of this study is therefore to determine whether the FMS has value as a predictor of injury within a professional rugby union player population.

Despite the widespread use of the FMS within sporting (27) and tactical (2) populations, recent research has questioned the validity of the use of the composite score (out of 21), as opposed to the use of individual test components. Kazman et al. (22) performed a factor analysis that indicated that the FMS test is not a unitary construct. This indicates that the test should be interpreted as 7 individual component tests with each test measuring a different quality, rather than a composite test reporting total quality of movement. Although a recent review has called for further verification of this finding (27), this would seem to make intuitive sense. For example, the SM test is likely to be more important for both injury risk and performance within a population of swimmers than it would be for runners. Recently published research by Hotta et al. showed that in a population of competitive male runners the composite FMS score was not predictive of injury, but a combination of the scores for the DS and ASLR tests was (21). Based on this finding, it seems that certain FMS component tests may be more relevant for injury risk than others within particular populations. This may be of practical importance to improving the specificity of the test within different groups. Therefore, a further aim of this study is to determine whether the use of an individual FMS component test, or a combination of component tests, is more appropriate than the use of the composite score for predicting injury risk in rugby union players.

The majority of injuries (≈80%) in rugby union are the result of contact events such as collisions and tackles (41). It has previously been assumed that contact injuries are unavoidable (14) because of the dynamic nature of forces involved. This assumption has led some researchers to exclude contact injuries from FMS injury analysis (38). However, a growing body of evidence within rugby union points to the presence of technique-related risk factors for contact injury (4,16,18,19,34,35). The presence of a dysfunctional movement pattern would therefore affect the ability of a player to tackle with optimal technique, which will likely affect the players' injury risk.

Noncontact injuries on the other hand, are typically soft-tissue injuries that result from excessive training loads and inadequate recovery (14). Athletes with poor neuromuscular control, core strength, or muscular imbalances are more susceptible to these types of injuries because of the repetitive loads imposed on top of these dysfunctional movement patterns (1). Because the FMS screen was designed to assess joint mobility and stability in various movement patterns (6,7), the test may be able to expose some of the neuromuscular control and muscular imbalance risk factors that contribute to noncontact injury. Although noncontact injuries represent a considerably smaller portion (≈20%) of the total injuries in rugby union (41), they still represent a good target for injury mitigation efforts. A final aim of this study is therefore to determine the value of the FMS (composite and component tests) in predicting contact and noncontact injuries within a group of professional rugby players.

Methods

Experimental Approach to the Problem

A prospective, observational, longitudinal design was used to assess the application of the FMS as a predictor of severe injury in professional rugby union players. Participants completed FMS tests before the start of competitive rugby competitions, and injuries to these players were monitored for 6 months after the test. Using receiver-operated characteristic (ROC) curves and 2 × 2 contingency tables, odds ratios, sensitivity, and specificity were calculated to determine the accuracy of the prediction.

Subjects

This research was conducted in conjunction with a professional South African rugby union team that competes in the Super Rugby, Currie Cup, and Vodacom Cup competitions (see www.sarugby.co.za for more information about the tournaments). Players representing this team were tested on 4 occasions (January 2011, July 2011, January 2012, and January 2013), during the preseason periods before the start of professional competitions. As is the nature of professional sport, new players were contracted and other players were released to play elsewhere over the course of the study. Only players who gained regular selection for the starting team during the relevant period of competition (selected >60% of matches for which they were available) were included in the study. In total, 62 players (Age 25 ± 3, Stature 1.87 ± 0.08 m, body mass 103.1 ± 13.1 kg) took part in the study across 4 testing periods. No player was tested on all 4 testing occasions (40 players were tested once, 16 tested twice, and 6 were tested thrice). All players were injury free when they participated in the FMS testing. Any player injured during the course of the study needed to have returned to full practice and match participation before being allowed to complete the subsequent FMS test. No recurrences of the same injury occurred within the players included in the study. A total number of 90 FMS tests were included in the final data set (January 2011 = 27, July 2011 = 29, January 2012 = 16, and January 2013 = 18 subjects). The University of Johannesburg Ethical Review Board approved this research, and informed consent was obtained from all players, including

Table 1. Mean scores of injured and noninjured players in FMS and individual component tests.*

	Injured, $N = 26$	Not injured, $N = 64$	Effect size
FMS composite score	13.2 ± 1.7†	14.5 ± 1.5	0.83, large
Deep squat	1.8 ± 0.7	2.1 ± 0.4	0.60, medium
Hurdle step	2.0 ± 0.4	2.1 ± 0.4	0.25, small
In-line lunge	2.0 ± 0.7†	2.3 ± 0.5	0.53, medium
Shoulder mobility	1.5 ± 0.6	1.7 ± 0.7	0.30, small
Active straight leg raise	1.8 ± 0.5†	2.2 ± 0.6	0.70, medium
Trunk stability push-up	2.3 ± 0.5	2.4 ± 0.6	0.17, trivial
Rotary stability	1.8 ± 0.5	1.8 ± 0.5	0.00, trivial

*FMS = Functional Movement Screen.
†indicates a significant difference between groups ($p < 0.05$).

permission for their data to be used for scientific investigation. The study conformed to the Declaration of Helsinki (2013) (41).

Procedures

All testing was conducted by a registered biokineticist and qualified FMS tester used by the team. Functional Movement Screen tests were recorded on video and analyzed using Dartfish video analysis software (Dartfish, Fribourg, Switzerland), to increase the reliability of measurement. Players were familiarized with the test before the start of the study. All players were tested within 1 week of each other on each of the 4 testing occasions. The composite score and the score for each of the FMS component tests was recorded. Players who scored ≤14 overall, or <2 on any component test, were recommended to follow "prehabilitation" programs to address their movement dysfunctions. These prehabilitation programs are a confounding factor in the study design, but were ethically required after the identification of potential injury risk factors. Compliance with the prehabilitation program was not enforced, and the effect of this intervention was not assessed in this study.

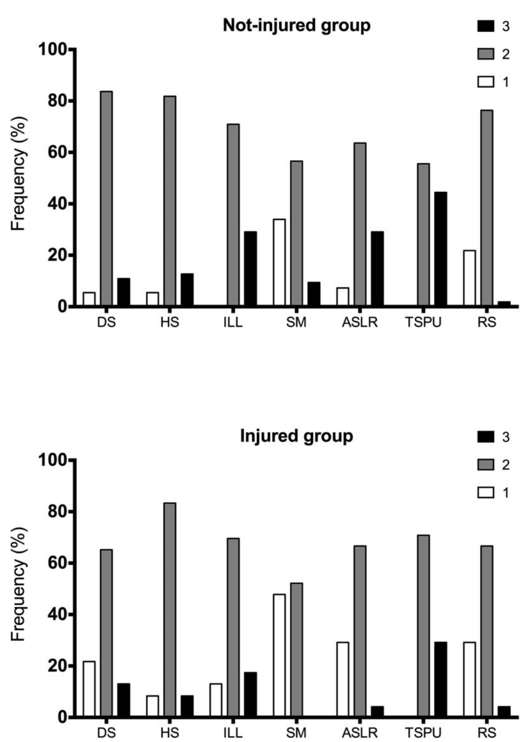

Figure 1. Frequency distribution of scores for Functional Movement Screen component tests of injured and noninjured groups.

The team medical doctor recorded injury data for the duration of the study according to the methods described in the International Rugby Board (IRB) consensus statement on injury definitions (12). Accordingly, data on the type, site, duration, and mechanism (contact or noncontact) of all injuries that caused players to miss part of matches or training for a period of time was recorded. For the purposes of the FMS analysis, only severe injuries were considered. A severe injury is defined as an injury that caused a player to be excluded from matches and/or practice for a period of 28 days or more (12). This distinction was made because previous studies using FMS to predict injury in contact sport had also only considered serious injuries (>20 days) (25). Only severe injuries that occurred within 6 months (180 days) of an FMS test were included in the analysis.

Statistical Analyses

Power analysis revealed that on the majority of test occasions (3 out of 4), there was insufficient power (>0.80) to illicit a real difference. For this reason, all the participants were pooled as a single test sample and analyzed using a linear mixed-model procedure. This procedure was chosen because of its ability to manage repeated measures with an inconsistent subject group (39). The data were processed to give each player a single observation on each occasion that they had an FMS test. Each observation had variables representing the test occasion (4 levels), player identity (62 levels), FMS score, and the grouping variable "Sustained Severe injury?" (Yes/No). Test occasion was treated as a repeated effect with a first-order autoregressive

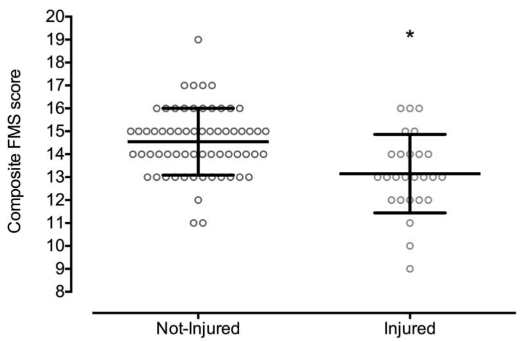

Figure 2. Composite Functional Movement Screen (FMS) scores of players not injured and players who suffered severe injury >28 days. Circles indicate individual composite scores; large error bars depict mean and *SD* of the composite FMS scores. Asterisk indicates significant difference between the 2 groups.

covariance type, whereas player identity was treated as a random effect. Estimated effect of the grouping variable is reported for all mixed-model analyses. The power of this analysis was calculated >0.95, when 90 observations were included.

The linear mixed-model procedure was used to determine if there was a difference in composite FMS and individual FMS component scores of players who suffered a severe injury and those who had not. The model was similarly applied to include only contact or noncontact injuries, and each individual component test. Data are presented as mean ± *SD*, and Cohen's effect size statistic is calculated to quantify the magnitude of the differences. Effect sizes of 0.2, 0.5, 0.8, and 1.2 were considered small, medium, large, and very large, respectively (20).

Receiver-operated characteristic curves were produced to assess the predictive ability of the composite FMS and individual FMS component test that were different between injured and noninjured groups. In addition, further short versions of the FMS test consisting of various combinations of the component tests, which were shown to be significantly different between injured and noninjured groups, were subjected to ROC testing.

Receiver-operated characteristic curves determine the cut-off score that maximizes the sensitivity (true positive rate) and specificity (true negative rate) of the tests as predictors of injury. For a diagnostic tool to be applied as a predictor of injury, the tool should maximize the chances of a correct prediction (True +'s) and minimize incorrect predictions (False +'s). A lower 1-specificity value reduces the number of false positives the test will produce, whereas higher sensitivity measures the number of injured cases that will be correctly predicted (True +'s). Therefore, the value with the highest sensitivity and lowest 1-specificity value is selected as the cut-off point. The method for producing a ROC curve is to produce cut-off values that are the average of 2 consecutive ordered test values; e.g., test values of 12 and 13 produce a cut-off value of 12.5. The final cut-off value is then between 2 half points, indicating precisely which whole number should be chosen. This value corresponds to the upper left line of the ROC curve.

All 90 FMS observations were included in the ROC curve analysis, despite the fact that repeat measures were performed on 22 of the players. These 22 players accounted for 28 tests included in the analysis. The result of the FMS test was different across test occasion in 24 of the 28 repeat tests. The authors felt that these differences indicated a sufficient amount of independence between tests for all samples to be included.

Contingency tables (2 × 2) were produced dichotomizing those who suffered a severe injury (injured) and those who did not (not injured) against those above and below the cut-off point determined by the ROC curve. Odds ratios, sensitivity, and specificity were then calculated. Chi-squared tests were used to determine whether there was a significant

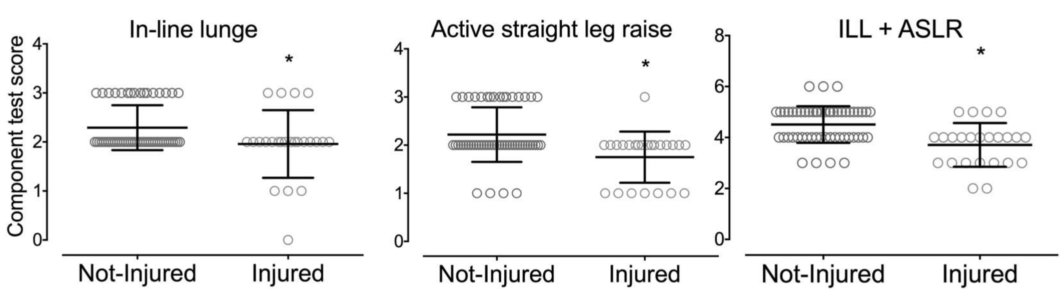

Figure 3. Distribution of test scores for in-line lunge, active straight leg raise, and the combination of the 2 tests (in-line lunge + ASLR) in injured and noninjured players. Circles indicate individual component scores, and large error bars depict mean and *SD* of the component scores. Asterisk indicates significant difference between the 2 groups.

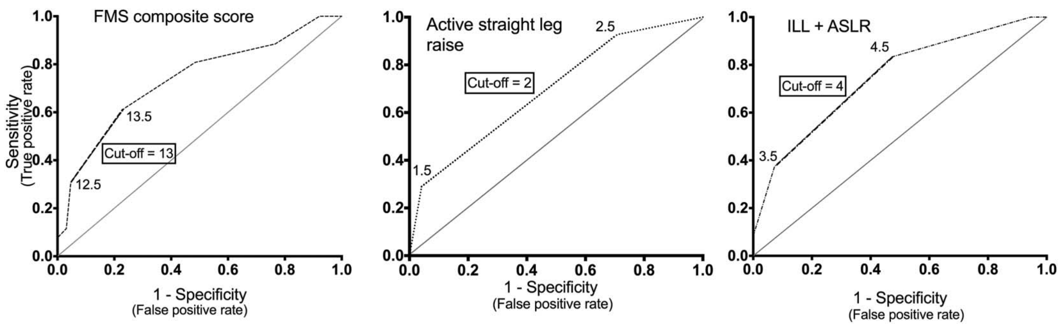

Figure 4. Receiver-operated characteristic curves for the FMS composite, active straight leg raise and in-line lunge + active straight leg raise score scores for the prediction of severe injury in rugby union players.

association between the test result and injury. Differences in the sensitivity and specificity of tests were determined by examining the degree of overlap in the 95% confidence intervals surrounding each value. In cases where overlap was less than 50% of the confidence interval arm, the difference was considered statistically significant (8).

All statistical analyses were performed using SPSS version 22 software (IBM, Inc.; Armonk, NY, USA). Statistical significance was set at $p \leq 0.05$ for all analyses. Wherever relevant, subject numbers (n) are presented. Mean FMS data are reported to one decimal place throughout. This step was taken to make the data more readily interpretable, but exaggerates the precision of the measurement, and as such is a limitation of the study. All mean FMS and component test scores should be interpreted in conjunction with Figure 1, which demonstrates the relative distribution of scores that make up the mean totals.

Table 2. 2 × 2 Contingency tables for FMS composite score, ASLR, and ILL + ASLR score as predictors of injury.*

	Injured	Noninjured
FMS composite score		
FMS ≤ 13	16	15
FMS ≥ 14	10	49
Active straight leg raise score		
ASLR ≤ 2	23	39
ASLR = 3	1	16
ILL + ASLR		
ILL + ASLR ≤ 4	20	26
ILL + ASLR ≥ 5	4	29

*FMS = Functional Movement Screen; ASLR = and active straight leg raise; ILL = in-line lunge.

Results

Functional Movement Screen Comparison of Injured and Noninjured Groups

The mean composite score for all FMS tests conducted over the course of this study was 14.1 ± 1.7 ($n = 90$), with a range of 9–19. A total of 26 severe injuries occurred over the course of the study. Table 1 presents the mean FMS composite score and the mean scores for each FMS component test for injured and noninjured player groups. There was a significant difference in composite FMS score between the injured and noninjured groups (injured 13.2 ± 1.7 vs. noninjured 14.5 ± 1.5, ES = 0.83, large) for all injuries. The difference in distribution of FMS scores for injured and not injured groups is illustrated in Figure 2.

To determine whether the difference in FMS composite scores was related to differences particular component tests, a frequency distribution analysis was performed (Figure 1). From these graphs, it is apparent that the injured group achieved a greater proportion of "1" scores in a number of component tests, including DS, ILL, SM, ASLR, and RS. Linear mixed-model analysis (Table 1) revealed that there were significant differences in the scores for "in-line lunge" and "active straight leg raise" between the injured and noninjured groups. Based on this result, a combination score for both these tests (ILL + ASLR) was created for further analysis. The differences in distribution of test results for ILL, ASLR, and the combination score are presented in Figure 3. The composite FMS, ILL, ASLR, and ILL + ASLR scores were carried forward for ROC analysis.

Receiver-Operated Characteristic Curves

Receiver-operated characteristic curves (Figure 4) were produced to determine the cut-off scores that maximize sensitivity and specificity of the FMS composite score and various component tests. It was determined that a cut-off of 13/14 maximized sensitivity and specificity of the test composite FMS score. Cut-off points of 2/3 and 4/5 maximized

Table 3. Predictive power of FMS composite, ASLR, and ILL + ASLR tests for severe injuries in professional rugby players.*

Test (cut-off value)	Area under the curve	Sensitivity (95% CI)	Specificity (95% CI)	Odds ratio (95% CI)	Chi-squared test, p
FMS composite (13/14)	0.73	0.62 (0.41–0.80)	0.77 (0.64–0.86)	5.2 (2.0–14.0)	<0.001
ASLR (2/3)	0.69	0.96† (0.79–1.0)	0.29† (0.18–0.43)	9.4 (1.2–76.0)	0.013
ILL + ASLR (4/5)	0.75	0.83 (0.63–0.95)	0.53†‡ (0.39–0.66)	5.6 (1.7–18.0)	0.003

*FMS = Functional Movement Screen; ASLR = and active straight leg raise; ILL = in-line lunge; CI = confidence interval.
†Indicates sensitivity or specificity that is significantly different from FMS composite score.
‡Indicates sensitivity or specificity that is significantly different from ASLR score.

sensitivity and specificity of the ASLR and ILL + ASLR tests, respectively. In-line lunge was statistically no better than chance at predicting injuries. The 2 × 2 contingency tables (Table 2) were produced using these cut-off values to determine which test provides the best predictive accuracy. The largest area under the curve for the 3 ROC curves presented was for the ILL + ASLR test (Table 3). The results of this analysis are presented in Table 3.

Contact and Noncontact Injuries

Following on from the original analysis, injuries were divided into 2 groups by injury mechanism (contact or noncontact), to determine the value of FMS in predicting these different types of injuries. Table 4 presents the results of linear mixed-model analysis for players sustaining severe contact or noncontact injuries. There was a significant difference in composite FMS scores of players who sustained severe contact injuries and those who did not (injured 13.1 ± 2.0 vs. noninjured 14.3 ± 1.5, ES = 0.76, medium). For noncontact injuries, there was no significant difference between the injured and noninjured groups (injured 13.3 ± 1.4 vs. noninjured 14.3 ± 1.7, ES = 0.60, medium). However, the p-value for this analysis was 0.06, indicating that the linear mixed-model analysis was tending strongly toward significance. In addition, the test values were almost identical to those for contact injuries and the effect size was the same (ES = medium). On the balance of evidence, it was decided to proceed as if there was a meaningful difference in the scores of injured and not injured players within the noncontact injury group.

When individual component tests were considered, there were significant differences in "deep squat," "in-line lunge," and "active straight leg raise" scores of players injured as a result of contact and noninjured players. Only "active straight leg raise" was different between injured by noncontact mechanisms and noninjured players.

Table 4. Mean scores of injured and noninjured players in FMS composite and component tests for contact injuries and noncontact injuries.*

	Contact injuries			Noncontact injuries		
	Injured, $N = 14$	Not injured, $N = 76$	Effect size	Injured, $N = 12$	Not injured, $N = 78$	Effect size
FMS composite score	13.1 ± 2.0†	14.3 ± 1.5	0.76, medium	13.3 ± 1.4	14.3 ± 1.7	0.60, medium
Deep squat	1.6 ± 0.8†	2.1 ± 0.4	1.04, large	2.1 ± 0.5	2.0 ± 0.5	0.20, small
Hurdle step	2.1 ± 0.3	2.1 ± 0.4	0.00, trivial	1.9 ± 0.5	2.1 ± 0.4	0.48, small
In-line lunge	1.8 ± 0.7†	2.3 ± 0.5	0.94, large	2.1 ± 0.7	2.2 ± 0.5	0.19, trivial
Shoulder mobility	1.5 ± 0.7	1.6 ± 0.7	0.14, trivial	1.4 ± 0.5	1.7 ± 0.7	0.44, small
Active straight leg raise	1.8 ± 0.6†	2.1 ± 0.6	0.50, medium	1.8 ± 0.5†	2.1 ± 0.6	0.51, medium
Trunk stability push-up	2.2 ± 0.4	2.4 ± 0.6	0.35, small	2.4 ± 0.5	2.4 ± 0.6	0.00, trivial
Rotary stability	1.9 ± 0.5	1.8 ± 0.5	0.20, small	1.6 ± 0.5	1.8 ± 0.5	0.40, small

*FMS = Functional Movement Screen.
†indicates a significant difference between groups ($p < 0.05$).

Table 5. Summary of the predictive power of FMS composite score and combinations of component test scores for severe contact and noncontact injuries in professional rugby players.*

	Area under the curve	Sensitivity (95% CI)	Specificity (95% CI)	Odds ratio (95% CI)	Chi-squared test, *p*
Noncontact injuries					
FMS composite (14/15)	0.68	0.83 (0.52–0.98)	0.46 (0.35–0.58)	4.3 (0.9–21.0)	0.0497
Contact injuries					
FMS composite (13/14)	0.71	0.71 (0.42–0.92)	0.72 (0.61–0.82)	6.5 (1.8–23.0)	0.003
DS + ILL (4/5)	0.73	0.92 (0.62–1.0)	0.37† (0.26–0.50)	6.5 (0.8–54)	0.049
DS + ASLR (4/5)	0.73	0.83 (0.52–0.98)	0.33† (0.22–0.45)	2.4 (0.5–12.0)	0.262
ILL + ASLR (4/5)	0.72	0.83 (0.52–0.98)	0.46† (0.34–0.59)	4.3 (0.9–21)	0.055
DS + ILL + ASLR (6/7)	0.76	0.83 (0.52–0.98)	0.52†‡ (0.40–0.65)	5.5 (1.1–27)	0.023

*FMS = Functional Movement Screen; CI = confidence interval; DS = deep squat; ILL = in-line lunge; ASLR = and active straight leg raise.

†Indicates sensitivity or specificity that is significantly different from FMS composite score.

‡Indicates sensitivity or specificity that is significantly different from DS + ASLR score.

In an attempt to determine whether a more parsimonious model of injury prediction could be found, ROC curves were produced to consider both the FMS composite score and the component tests that were significantly different as predictors of contact or noncontact injuries. In the case of contact injuries, because 3 component tests were shown to be different between the injured and noninjured groups, all combinations of DS, ILL, and ASLR were also tested.

Receiver-operated characteristic curve analysis revealed that for noncontact injuries the appropriate FMS composite score cut-off was 14/15. Active straight leg raise score was not statistically predictive of noncontact injuries. For contact injuries, the FMS composite score cut-off was 13/14. No individual component tests were statistically able to predict severe contact injuries. Component test combinations DS + ILL, DS + ASLR, ILL + ASLR all shared the same cut-off point (4/5), and the combination of all significant component tests DS + ILL + ASLR had a cut-off of 6/7.

The 2 × 2 contingency tables were produced to assess the predictive value of these cut-off points. These results are summarized in Table 5. For noncontact injuries, an FMS cut-off score of 14/15 predicted injury with an odds ratio of 4.3 (95% confidence interval [CI] = 0.9–21.0). For contact injuries, an FMS cut-off score of 13/14 predicted injuries with an odds ratio of 6.5 (95% CI = 1.8–23.0). The DS + ASLR and ILL + ASLR component test combinations showed no significant difference in test score distributions between contact injured and uninjured groups, although the ILL + ASLR was tending toward significance. The DS + ILL and DS + ILL + ALSR component combinations displayed significant contact injured vs. noninjured group effects.

Discussion

The aim of this study was to determine whether the results of an FMS test may indicate injury risk in professional rugby union players. Functional Movement Screen test results were compared with records of injuries that occurred in the 6 months after testing. It was determined that the mean composite FMS scores of players who suffered severe injury were significantly lower than the scores of those players who did not (injured 13.2 ± 1.7 vs. noninjured 14.5 ± 1.5, ES = 0.83, large). In addition, it was determined that there were no differences in 5 of the 7 FMS component tests between injured and noninjured players. There were significant differences in the ILL (injured 2.0 ± 0.7 vs. noninjured 2.3 ± 0.5, ES = 0.53, medium) and ASLR (injured 1.8 ± 0.5 vs. noninjured 2.2 ± 0.6, ES = 0.70, medium) component tests. This information questions whether all 7 FMS component tests are necessary for injury determination. A shortened FMS test consisting only of the significant component tests may be more appropriate for injury determination.

Since Kazman et al. found that the FMS test is not a unitary construct, it would seem prudent to consider the components of the test individually rather than as a collective score. In terms of injury risk management, it is more valuable for practitioners to understand which particular movement dysfunction causes the injury risk factor, rather than to link risk to a "global" movement quality score. This allows for the actual risk factor to be addressed and mitigated more accurately. Recent research in competitive male runners has shown that a combination of DS and ASLR scores were predictive of injury, but the FMS composite score was not (21).

Analysis of the component tests indicated that the ASLR and the combination of ILL and ASLR tests were predictive of injury. The ASLR test had the highest sensitivity (0.96, 95% CI = 0.79–1.0) of the 3 tests examined. This indicates that the ASLR test detected 96% of the players who suffered severe injury. High sensitivity of a test is very important when trying to identify treatable conditions (29). This analysis also revealed that the odds of severe injury are 9.4 times greater for players with an ASLR score ≤2. Because this movement dysfunction could likely be modified with appropriate training, it seems that this could be a very useful screening tool to inform injury risk management.

On the other hand, the specificity of this test was low (0.29, 95% CI = 0.18–0.43), indicating that a large number of players who were below the ASLR cut-off point did not suffer severe injuries. If practically applied, this would mean that a large number of players would be subjected to additional training to improve their hamstring flexibility and/or hip mobility, even though they may never have developed a related injury. In cases where a test possesses high sensitivity, but low specificity, it is suggested that a follow-up test with high specificity be conducted on patients who fail the original test (29). In this context, if players were only asked to perform the ASLR test and scored ≤2, they could then be asked to perform additional FMS component tests. The addition of the ILL to the ASLR test (ILL + ASLR) test significantly increased the specificity of the screen from that of the stand-alone ASLR test (ASLR specificity = 0.29, 95% CI = 0.18–0.43 vs. ASLR + ILL specificity = 0.53, 95% CI = 0.39–0.66, $p \leq 0.05$). Because the active straight-leg raise seems to be the most powerful of the FMS component tests in this context, efforts to improve the reliability of this test through increased standardization of test conditions and the use of equipment such as goniometers may improve the test specificity.

No other component tests demonstrated a significant difference between the injured and not injured groups. However, including the other 5 component tests (FMS composite model) leads to further increases in the specificity of the injury prediction model, with concurrent reductions in the model sensitivity. This indicates that the addition of the nonsignificant component tests to the injury prediction model does affect the overall predictive quality of the model. It is possible that other component tests within the FMS also affect injury risk for rugby players but that these were not revealed in this analysis because the sample size was not large enough to demonstrate the effect. Therefore, practitioners may want to experiment with the inclusion of other FMS component tests to further refine their own prediction models. However, on the basis of this analysis, it seems that active straight-leg raise and ILL are the 2 component tests that are critical for injury prediction in rugby union players.

The identification of ASLR score ≤2 as a risk factor for severe injury in professional rugby union players is a valuable step toward reducing injury risk. Research has shown that low FMS component test scores can be improved through corrective training programs (5,24). The next step, therefore, is to determine whether a training program that improves ASLR and ILL scores would also reduce severe injury incidence among these players.

A unique aspect of this research study is the assessment of the ability of FMS to predict contact injuries. It has previously been assumed that FMS would only be related to noncontact, overuse-type injuries (38). However, mixed-model analysis in this study showed that there was a significant difference in composite FMS scores of players who suffered severe contact injury vs. those who did not (injured 13.1 ± 2.0 vs. noninjured 14.3 ± 1.5, ES = 0.76, medium). Receiver-operated characteristic analysis indicated that players with a composite FMS score of ≤13 are statistically more likely to sustain a contact injury (odds ratio = 6.5, 95% CI = 1.8–23.0).

Analysis of the individual component tests indicated that there were significant, medium- to large-sized differences in DS, ILL, and ASLR between contact injured and noninjured groups. The sensitivity of the DS and ILL (DS + ILL) combination score was the highest (0.92, 95% CI = 0.62–1.0), but not significantly different to any of the other screening tests. The addition of the active straight-leg raise to the DS + ILL score made a significant improvement in the test specificity (DS + ILL specificity 0.37, 95% CI = 0.26–0.50 vs. DS + ILL + ASLR specificity 0.52, 95% CI = 0.40–0.65, $p \leq 0.05$). Once again the addition of nonsignificant FMS component tests increased the model specificity (0.72, 95% CI = 0.61–0.82), which may indicate that another test that affects injury risk was not revealed because of the small sample size.

The ability of combinations of the FMS component tests to predict contact injuries is a surprising result. Because the majority of collision sport injuries occur during physical collisions and tackles, they are generally thought unavoidable (14). However, these results suggest that there may be a movement quality component that is related to the occurrence of certain severe contact injuries.

The authors would like to propose a potential mechanism as to how dysfunctional movement patterns, as demonstrated by these FMS component tests, may affect contact injury incidence in rugby union. First, tackling is a highly technical skill that requires high coordination to be executed safely (18). Tackling is one of the major mechanisms of injury in rugby union (40), but injury incidence is not related to the number of tackles a player performs (15). This suggests that injury risk may be related to how well a player executes tackles rather than how often he tackles. Recent research by Burger et al. demonstrated that rugby union players who were injured during tackles displayed a number of technical errors during those tackles (3).

It is still likely that certain scenarios remain where contact injuries occur independent of player skill and technique factors and thus remain unavoidable. However, the models presented here make an argument for how tackle injuries may be related to particular dysfunctional movement patterns. The data collected for this study divided injuries into contact and noncontact mechanisms, but did not further describe the mechanism of injury. To further investigate the relationship between FMS component movement patterns and tackle injuries, future research should aim to include data relating to the nature of contact, how late in the game they occurred, the fatigue status of the player, and whether any manageable technical and/or co-ordination factors were at fault.

A final finding of this study was that the FMS composite score was statistically predictive of severe noncontact injuries, but none of the individual component tests or combinations thereof produced a similar result. Considering that Kazman et al. determined the FMS composite score is not a unidimensional construct, this result should be considered cautiously. Previous research has found that FMS score is not related to the occurrence of noncontact (21,37) or overuse (31,32) injuries but did increase the predictive value of an overuse injury model (31). Theoretically, the FMS screen should predict noncontact and/or overuse injuries better than it does contact injuries because these are directly affected by movement patterns that the FMS test purports to measure (32). More research is required to determine how FMS relates specifically to noncontact injuries.

An area to consider when comparing this study with others examining the relationship between FMS and injury is the differences in the definition that was applied for injury. The IRB definition of severe injury (>28 days) (12) applied here is longer than the "serious" injury (>21 days) used by Kiesel et al. but similar to the "4 weeks" applied by Hotta et al. Other studies have defined injuries as events that require medical attention (5) and any injury that caused a missed participation (30). It seems that the link between low FMS scores and injury does not become apparent in contact sports such as American football and rugby union until the severity of the injury is included in the analysis. This is possibly because exposure to contact sport inevitably results in a number of relatively minor injuries like contusions and lacerations, which create a degree of "noise" within the number of injuries sustained.

The mean composite score for the rugby union players in this study (14.1 $\pm$ 1.7) was lower than the scores that have been previously reported in team sports such as American football (16.9) (25), Gaelic field sports (15.5 $\pm$ 1.5) (11), and an active general population (15.7 $\pm$ 1.9) (30). However, our result is similar to that reported for female collegiate athletes (14.3 $\pm$ 1.8) (36). It may be that these differences relate to the different training regimens followed by athletes in different sports or may be related to the cohort studied. Further differences between this study and others are in the FMS component tests identified as being important for the identification of injury. This investigation identified DS, ILL, and ASLR as being important in professional rugby players. Hotta et al. identified DS and ASLR as relevant for competitive distance runners, and Warren et al. identified ILL as related to injury in division 1 athletes. These findings underline the fact that there are differences in the physical attributes and training regimens of athletes in different sports and confirm that it is incorrect to merely apply the FMS results determined in different populations across all other sports. Rather, FMS applications should be considered to be sports specific, taking into account the demands of the sport and participants.

This research adds to the growing body of evidence for the predictive value of FMS component tests for injuries (5,21,23,25,30,32). Although some studies have failed to establish this link (26,38), there is sufficient positive evidence for the application of this test to warrant its use in professional team settings. The findings of this research suggest that professional rugby union players are more likely to sustain both severe injuries, particularly contact injuries, if they score poorly on the DS, ILL, and active straight-leg raise FMS component tests.

Practical applications

Poor DS, ILL, and ASLR scores are identifiable risk factors for severe injury in professional rugby union players. These findings have implications for the responsible management of players. The ASLR test is the most sensitive test for identifying players at risk of injury, but its specificity is poor. Players performing poorly in this test should be subjected to additional assessments to attempt to quantify their injury risk. "At-risk" players should be placed on corrective exercise programs. Although it has not yet been established that improving scores in individual FMS component tests reduces individual injury risk, it seems prudent to attempt to modify this risk factor. Research has shown that FMS scores improve with corrective exercise programs (5,24). In addition, "at-risk" players could be managed through additional recovery time or treatments and could have their game and training loads reduced to minimize risk. Further research on whether modifying FMS score reduces injury risk is recommended.

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