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Sport Science Lab® Screening Protocol: The association between physical fitness Parameters and injury among elite rugby players



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ABSTRACT

Context and objectives: The Sport Science Lab® (SSL®) screening protocol includes novel methods of assessing flexibility, strength, plyometric ability and rugby specific fitness. The objective of this study was to investigate the association between these tests and injury among professional rugby players.

Design: Prospective cohort study.

Setting: Fitness facilities of participating teams.

Participants: Thirty-nine injury-free, elite, adult (>18 years), male rugby players.

Main outcome measures: The test battery consisted of eleven flexibility-, nine strength- and six plyometric tests and a rugby specific fitness test (RSFT). Injuries were recorded weekly during the 2019 rugby season. Associations between test results and injuries were analysed utilising suitable tests of association i.e., sensitivity, specificity, false positive rate, false negative rate, positive predictive value and negative predictive value and odds ratios (OR) (with confidence intervals (CI)). Bivariate correlations and logistic regression were performed to assess the relationship of the predictor variables to the outcome.

Results: Players who achieved the set standard for the RSFT (OR = 3.17; 95% CI = 0.79–12.75), triple horizontal broad jump (OR = 2.40; 95% CI = 0.86–19.61) and lateral depth jumps (OR = 2.40–3.44; 95% CI = 0.53–18.84) were two to three times less likely to sustain an injury during the season.

Conclusion: Players with superior rugby specific fitness and cyclic linear- and lateral plyometric ability, may have a decreased risk of sustaining injuries.

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1. Introduction

Rugby union (hence forth rugby), is a physically demanding sport played internationally at professional level (Whitehouse et al., 2016). Considering the sport's collisional nature and multifaceted physical fitness challenges, the incidence of injury in rugby is high (Kaplan et al., 2008). At professional level, prospects of victory at prestigious national and international competitions and the potential monetary spur, inevitably influence the level of play and in turn injury risk (Garraway, 2000). The upsurge in injury incidence at elite level is subject to increased speed, strength and endurance requirements essential to compete at elite level (Garraway, 2000). Injury risk can be mitigated through injury prevention strategies which include injury screening (Gabbett & Domrow, 2005; Gabbett, Ullah, & Finch, 2012a, 2012b; Quarrie, 2001a, 2001b).

Despite the methodological and statistical limitations impeding screening protocols' predictive validity (Bahr, 2016; Nielsen et al., 2020; Verhagen et al., 2018), Bahr and Verhagen et al. (Verhagen et al., 2018) reiterates several additional reasons, including medicolegal duty and establishing athlete rapport (Bahr, 2016; Verhagen et al., 2018), why screening remains a vital component in the injury prevention paradigm. Biostatisticians and epidemiologists should therefore continue efforts to develop methodology to facilitate studies that aim to identify associations between MSK screening tests and injury. Simultaneously, medical and conditioning professionals should strive to identify MSK risk factors and design corresponding tests to quantify the level of injury risk associated with such factors.

Rugby specific musculoskeletal (MSK) screening protocols (Gray & Naylor, 2012), have been implemented by various international rugby unions (Gray & Naylor, 2012; Quarrie, 2001a, 2001b). Screening of athletes allow for early identification of possible modifiable intrinsic injury risk factors and thereby contribute to overall injury prevention tactics (Bahr, 2016; Olivier & Gray, 2018).

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MSK screening protocols, like the South African Boksmart programme, typically imposed by sport medical professionals include the evaluation of modifiable intrinsic risk factors such as posture, strength, range of motion (ROM) and joint alignment during the execution of movement (e.g. drop jump test) (Gray & Naylor, 2012). While sporting authorities (Verhagen et al., 2018) recommend preseason screening, there are few studies investigating the effectiveness of these protocols. One study (Brown et al., 2017) investigating the effectiveness of the nationwide BokSmart rugby injury prevention programme on catastrophic injury, found no significant difference in injury rates among senior players pre-and post-implementation. Furthermore, developers' rationale for the inclusion of most of the tests are often based on the tests' reliability (Gray & Naylor, 2012) or relationship to injuries among sporting populations other than rugby or at participation levels other than elite level (Gabbett & Domrow, 2005; Yeomans et al., 2019).

Upon designing the SSL® screening protocol, possible reasons for inconsistencies in research related to MSK tests' association to injury were considered (Olivier & Gray, 2018). Methodological barriers include limitations of current statistical methods that account for the complexity of sports injuries and temporality of risk factors (Bahr, 2016; Nielsen et al., 2020; Verhagen et al., 2018). The researchers hypothesise, that in addition to these barriers, tests usually included in medical MSK screening protocols might not sufficiently reflect the functional similarities (including joint angles, mechanics and muscle actions related power and force production) of on-field activities. The MSK aspects being tested are therefore not tested in a manner that is sufficiently similar to the way different anatomical structures or physiological processes will be challenged during participation in the sport. While screening tests should consider players' safety, the level of intrinsic risk associated with non-contact activities, should also be reflected by the tests. Screening tests that, for example, don't require players to produce near optimal force and power, may not expose neuromusculoskeletal deficits when required to produce power where the magnitude is more closely related to rugby specific activities.

Tests related to physical fitness might be more synonymous with rugby related activities in terms of movement patterns, mechanics, and power production.

Based on the above and previous research (Gabbett & Domrow, 2005; Gabbett et al., 2012a, 2012b; Quarrie, 2001a, 2001b), the developers of the SSL® screening protocol, propose that players who achieve better results for tests measuring physical fitness constructs, also have decreased injury risk. A series of linear and lateral plyometric tests and a rugby specific cardio-respiratory fitness test (RSFT) (as described in Appendix A), in addition to isolated strength and flexibility tests (described elsewhere) (MacMillan et al., 2021) have therefore been included in this protocol. Deficits in strength and flexibility resulting in faulty biomechanical patterns (and vice versa), might not only compromise athletes' physical fitness but also increased their risk of sustaining injuries risk (Gabbett et al., 2012a, 2012b; Quarrie, 2001a, 2001b). Tests assessing players fitness, including strength, flexibility, plyometric/power and cardio-respiratory ability, are included in conditioning (non-medical) screening protocols. A recent systematic review (Chiwaridzo et al., 2020) however, highlighted the lack of strong evidence confirming the reliability and validity of tests currently used to gauge players fitness. Novel methods of assessing players strength, flexibility, plyometric and cardiorespiratory ability have therefore been included in the SSL® Screening protocol.

In addition to the physiological rationale and evidence related to the quality of screening test properties, the practicality (i.e., ease and duration of execution, need for less and inexpensive equipment, space as well as examination skill required) should also be considered. To design a user-friendly and scientifically sound MSK

screening tool that could be used by both medical and conditioning professionals, the SSL® screening protocol was developed. One of the first steps to validate screening tests involves establishing relationships between test outcomes and injury (Bahr, 2016). This study set out to investigate the association between the tests included in the SSL® protocol and injury risk among professional rugby players.

2. Methodology

2.1. Study design and setting

This was a prospective longitudinal cohort study. Data were collected at the fitness facilities of the respective participating teams.

2.2. Participants

Elite (contracted by one of the official South African rugby unions), adult (between the ages of 18 and 36) male rugby players participating in the annual inter-provincial (Super Challenge) and/or international rugby (Super Rugby) tournaments, who were injury free at the start of the competitive season were included in this study. Participants who were not on the active team roster at the start of the competitive rugby season were excluded.

A sample size of 35 was calculated as follows: Effect sizes (ES) were calculated using Cohen's *d*, where ES of 0.20, 0.50 and 0.80 were respectively interpreted as small, medium, and large. A priori power analysis, using G-power related to the medium effect size (ES = 0.50) was used for the sample size calculation. A power analysis for estimating a sample size that would yield a power of 80% was conducted. To account for drop-out, the researchers decided on a sample size of 40 participants.

Information regarding the study was sent to fourteen official national rugby unions and requested that teams who volunteer send through a list of potential participants. Two teams volunteered and players who met the inclusion criteria were recruited.

2.3. Procedures

Ethical approval was granted from the local tertiary institution's Human Research Ethics Committee (Medical). Written informed consent was obtained from the rugby union and players who volunteered to participate in the study.

2.3.1. Pre-participatory screening tests

The study commenced two weeks prior to the start of the 2019 competitive rugby season and consisted of two phases. Firstly, all participants were requested to complete a self-administered pre-season questionnaire consisting of general information regarding the players position, team, upper and lower limb dominance as well as information regarding the status, nature, and prevalence of any previous injuries.

Thereafter, all players performed each of the screening tests (eleven flexibility-, seven strength-, six plyometric- and one rugby specific cardio-respiratory fitness tests) included in the SSL® Screening protocol. The screening lasted approximately 1 h. A description of the flexibility and strength tests as well as rationale for inclusion in the SSL® screening protocol has been published elsewhere (MacMillan et al., 2021), while that of the plyometric and the rugby specific fitness (RSFT) tests, is set out in Appendix A and B (supplementary online material) respectively.

Testing was conducted and rated or measured by the researcher, a qualified physiotherapist with more than five years' experience and who is familiar with the use of the SSL® screening protocol in

daily clinical practice. For time efficiency all strength and flexibility tests required to be done on the floor were done first, followed by the tests in standing, then tests performed on the plinth and lastly all plyometric tests. Athletes were allowed three attempts at each of the tests and the best attempt was recorded. To account for possible effects of fatigue, rests periods of 2 min between the three attempts of each of the plyometric tests were allowed. The plyometric tests were performed in the following order: vertical jump, static-to-vertical jump, depth jump, lateral depth jumps, triple horizontal broad jump and lastly lateral side-to-side hurdle jumps. For practical purposes, the RSFT was done in groups of three players at a time. Two research assistants assisted with recording the results of the RSFT. Players were screened over three days, before any team training sessions. All test results were recorded on a specifically designed data capture sheet.

2.3.2. In-season injury surveillance

For the duration of the in-season competition (nineteen weeks), members of the teams' medical staff were requested to complete the in-season injury surveillance questionnaire weekly. This questionnaire was designed to collect information regarding the nature of in-season injuries, the extent of the injury (medical attention required and dismissal from participation) and the mechanism of injury. This questionnaire was based on the Boksmart injury surveillance questionnaire (Gray & Naylor, 2012) for which the construct and content validity for injury surveillance among cricketers have been established.

2.3.3. Injury definition

For the purposes of this paper an injury was defined as rugby related musculoskeletal bodily harm or damage causing a player to miss at least one scheduled game (Gabbie et al., 2006a, 2006b; Gabbett & Domrow, 2005; Gastin et al., 2015). While all injuries (regardless the time-loss consequence) were captured and summarised, only those which resulted in match-time loss were utilised for the calculation of statistics of association.

2.4. Data analysis

Statistical procedures were performed using STATA Data Analysis and Statistical Software (version 11.2; Texas: USA). Once captured, data were visually inspected for extreme values.

2.4.1. In-season injury incidence

Injuries sustained during the season were analysed (count and percentage) according to body area, nature, mechanism of injury and severity (in terms of training- and game-time loss). Injury incidence was calculated as the number of injuries per 1000 player hours. The number of training and game hours was collected weekly from the teams' game lists and training schedules.

2.4.2. Anthropometric and demographic data

Descriptive statistics for participants' age, height, weight, and BMI were analysed. Shapiro-Wilks test confirmed normality of data. Injured vs non-injured players' anthropometrics (height, weight, BMI) and age were compared using the independent *t*-test assuming unequal variance.

2.4.3. Relationship to previous injury

Considering the sample size and resultant small cell counts, the Fisher's exact test (as oppose to Chi-square test) was performed to explore the relationship between in-season injury sustained and injury history. Relative risk was calculated as the risk of injury when exposed to previous injury divided by risk of injury when not exposed to previous injury (Olivier & Gray, 2018).

2.4.4. Results of screening tests and association to in-season injury

Continuous variables were summarised by mean, standard deviation (SD) and range. Categorical variables (binary and ordinal data) were summarised by frequency counts and percentages. Static-to-vertical jump, lateral jump and triple horizontal broad jump distances were summarised as a percentage of the players height (i.e., jump distance/player height $\times$ 100). Depth jump heights were displayed as a percentage of the static-to-vertical jump height (i.e., depth jump distance/static-to-vertical jump distance $\times$ 100).

The chi-squared test for categorical measures, independent *t*-tests (for normally distributed data) and Mann-Whitney U tests (for skewed data) were used to determine the between groups (injured vs non-injured) potential predictor variable (screening test results) differences. Where applicable, appropriate effect sizes (depending on the normality of data) were also calculated 0.20, 0.50 and 0.80 respectively interpreted as small, medium and large (Pautz et al., 2018).

Bivariate correlations were performed to assess the relationship of the predictor variables to the outcome. Variables with correlations of which $p < 0.2$ were included in the logistics regression models. Multiple regression analysis was not viable as only data for 39 participants were complete.

Associations between test results and in-season injury incidence were also analysed by the construction of 2×2 contingency tables relating the achievement of the proposed minimum standards for each of the tests and in-season injury incidence. The following statistical measures were calculated for such a table: sensitivity, specificity, false positive rate (FPR), false negative rate (FNR), positive predictive value (PPV) and negative predictive value (NPV) and odds ratios (OR). Receiver operating characteristic (ROC) curves were calculated for continuous variables in cases where the proposed minimum standard (i.e., cut-off) did not yield sufficient sensitivity and specificity values to confirm association. Confidence intervals and *p*-values are presented.

3. Results

3.1. Participants

Screening data for one participant was incomplete and therefore not included. A total of 39 (out of 40) rugby players with a mean age of 20.36 years participated. Injury surveillance data for all 39 players was complete for the entire follow-up period. Descriptive statistics for anthropometric data and age for injured vs non-injured players are summarised in Table 1. There were no significant differences between injured and non-injured players.

3.2. Injury incidence

The total combined injury incidence rate during training or match occurrence was 10.50/1000 player hours. In total, 27 players (89.74%) sustained 43 injuries. Twenty-seven players (69.23%) sustained 33 injuries (76.74%) which caused them to miss one or more matches. Fig. 1 broadly illustrates the number of players who sustained injuries as well as the number of injuries, matches missed because of the injuries, type of injury and body areas affected. A detailed layout of the sub-categories is summarised in Appendix C (online supplementary material). Most of the injuries were acute contact injuries (37.00%) and were sustained while being tackled by another player 10 (23.26%). The lower limbs (74.41%) were the most frequently affected body area.

3.3. Injury risk factors

No significant difference was found between players who

Table 1
Anthropometric and Demographic data for injured vs non-injured players.

	All players (n = 39)	Injured (n = 27)	Not Injured (n = 12)	t-test	Effect Size
	Mean ($\pm$ SD)	Mean ($\pm$ SD)	Mean($\pm$ SD)	P-Value	
Weight (kg)	99.07($\pm$ 13.94)	97.89($\pm$ 10.96)	101.43($\pm$ 19.44)	0.71	0.15
Height (cm)	186.18($\pm$ 8.50)	185.67($\pm$ 8.05)	187.33($\pm$ 9.70)	0.61	0.19
Age (years)	20.36($\pm$ 1.93)	20.33($\pm$ 2.04)	20.42($\pm$ 1.73)	0.97	0.01
BMI (kg/m ²)	28.75($\pm$ 2.93)	28.58($\pm$ 2.84)	29.13($\pm$ 3.23)	0.62	0.19

BMI = Body mass index.

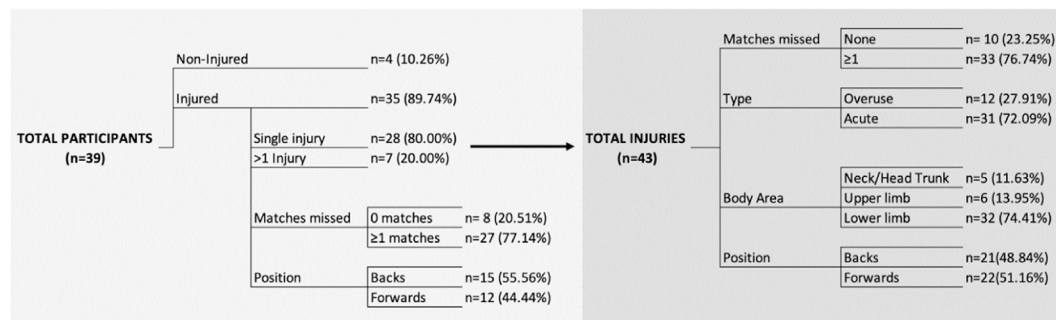


Fig. 1. Summation of number of participants injured and injuries sustained.

sustained previous injury and those who did not. However, the relative risk ratio (RR) of sustaining an injury during the season was 1.45 times higher for players with a history of injury (RR = 2.63; 95% CI 1.09; 6.04).

Descriptive statistics for all tests with continuous outcomes and the differences between injured and non-injured players are summarised in Table 2. The count and frequency of players who achieved the proposed minimum standards for each of the tests is summarised in Appendix D (supplementary online material).

The only significant difference in test results between injured and non-injured players were the combined shoulder rotation ROM test ($p = 0.04$; ES = 0.95) and RSFT (Chi X (Kaplan et al., 2008) = 2.89; $p = 0.09$). Regarding the distance (meters) covered during the performance of the RSFT, the non-injured group (737.08 ± 69.46) exceeded that of the injured groups (703.15 ± 69.46).

Oblique strength, left and right lateral depth jump and the RSFT had bivariate correlations with p -values of <0.20 and were subsequently considered for logistic regression analysis (Table 3). From these results most markedly, players who did not achieve the proposed position specific RSFT minimum standard was 3.32 times more likely to sustain an injury during the season.

Statistics of association as calculated from 2×2 contingency tables based on the proposed minimum standards of all tests are summarised in Appendix E (online supplementary material). All plyometric tests and RSFT (Table 4) had OR's indicating that players who achieved or didn't achieve the proposed minimal standards were at least twice as likely to sustain in-season injuries. The results should, however, be interpreted with caution as the respective associated CI's were large.

4. Discussion

In rebuttal to Bahr's review (Bahr, 2016), Verhagen et al. (Verhagen et al., 2018) provides several reasons (including establishing players' fitness baseline in their healthy state) for the importance of pre-screening for individual athletes. Ekstrand et al. (Ekstrand et al., 2019) highlights that poor communication

between medical staff and team managers (coaches and conditioning professionals) increase players' risk of injury. The SSL® screening protocol attempts to bridge the possible medical-conditioning-staff-gap by including strength, flexibility, and athletic performance related tests, thereby providing a more holistic depiction of players' physical fitness to both medical and conditioning professionals prior to the start of the competitive season. This study investigated the association between the individual tests included in this protocol and injury incidence.

4.1. Injury incidence

Overall injury incidence rates in this study (10.50/1000 player hours) was higher than that reported for professional Australian (Whitehouse et al., 2016) (6.69/1000 players hours) and South African (Schwellnus et al., 2014) (9.20/1000 players hours) teams respectively participating in the 2014 and 2012 Super Rugby competitions. The differences in injury incidence rate might be related to differences in players' conditioning levels or movement characteristics in terms of distance covered and velocity at which distance is covered (Whitehouse et al., 2016). Additionally, the difference in number of training sessions or games played (i.e. opportunity to sustain injuries) per team during the respective seasons may explain the difference in injury incidence.

While the above studies also reported the lower limb as most frequently injured anatomical area, the percentages (57.00% (Whitehouse et al., 2016) and 48.10% (Schwellnus et al., 2014), respectively) of total injuries were much lower compared to this study (74.41%). Possible reasons may be the difference in game plan of the teams investigated in the last-mentioned studies compared to the teams included in this study. A "tight" game in which the ball is carried to retain possession, might yield less risk of lower limb injury than a "running" game where players run and pass the ball to gain territorial advantage.

Like this study, several studies (Brooks, 2005; Fuller et al., 2007a; Whitehouse et al., 2016) reported that being tackled was the most frequent cause of injury. This could be related to the high frequency of tackling events compared to other contact sports

Table 2

Descriptive statistics for tests with continuous and ordinal outcomes and differences between injured vs non-injured players.

Continuous variable tests	All players (n = 39)	Injured (n = 27)	Non-Injured (n = 12)	P-Value	Effect size
	Mean ($\pm$ SD)	Mean ($\pm$ SD)	Mean ($\pm$ SD)		
Flexibility (distance in cm)					
Ankle DF - R	9.92($\pm$ 3.18)	10.22($\pm$ 2.21)	9.25($\pm$ 4.77)	0.87	0.29
Ankle DF - L ¹	9.67($\pm$ 3.26)	9.59($\pm$ 2.62)	9.83($\pm$ 4.53)	0.87	0.08
Hamstrings	-0.05($\pm$ 10.00)	0.81($\pm$ 11.16)	-2.00($\pm$ 6.71)	0.36	0.28
V-Sit ¹	42.15($\pm$ 11.47)	42.07($\pm$ 11.87)	42.33($\pm$ 11.02)	0.95	0.02
Combined Shoulder Flexion ¹	30.97($\pm$ 11.03)	30.96($\pm$ 11.38)	31.00($\pm$ 10.70)	0.20	0.55
Combined Shoulder Extension ¹	37.54($\pm$ 11.04)	39.00($\pm$ 10.28)	34.25($\pm$ 12.42)	0.21	0.5
Combined Shoulder mobility - R	6.46($\pm$ 7.49)	6.44($\pm$ 7.37)	6.50($\pm$ 8.08)	0.21	0.95
Combined Shoulder mobility - L	8.28($\pm$ 7.41)	7.56($\pm$ 6.60)	9.92($\pm$ 9.07)	0.21	0.29
Strength (number of repetitions)					
Abdominals	20.08($\pm$ 5.34)	20.15($\pm$ 5.33)	19.92($\pm$ 5.62)	0.62	0.04
Obliques	17.49($\pm$ 4.80)	17.78($\pm$ 5.16)	16.83($\pm$ 4.00)	0.11	0.19
Plyometrics					
Static-to-vertical jump (STVJ) ¹					
(% of player height)	34.63($\pm$ 5.12)	34.80($\pm$ 5.34)	34.24($\pm$ 4.78)	0.66	0.11
Depth jump (% of STVJ)	98.77($\pm$ 12.26)	98.94($\pm$ 11.88)	98.39($\pm$ 13.62)	0.75	0.12
Lateral Depth Jump - ¹ (% of player height)	85.39($\pm$ 7.46)	84.16($\pm$ 6.78)	88.16($\pm$ 8.46)	0.80	0.04
Lateral Depth Jump – (% of player height)	85.65($\pm$ 9.18)	84.74($\pm$ 7.82)	87.71($\pm$ 11.82)	0.17	0.55
Triple horizontal broad jump (Whitehouse et al., 2016) (% of player height)	411.26($\pm$ 37.74)	409.90($\pm$ 43.75)	414.34($\pm$ 19.52)	0.55	0.28
Rugby specific fitness test (distance in m)	713.59($\pm$ 73.32)	703.15($\pm$ 69.46)	737.08($\pm$ 79.36)	0.20	0.13
Ordinal variable tests (Scale 1–5)					
	All players (n = 39) Mode (Range)	Injured (n = 27) Mode (Range)	Non-Injured (n = 12) Mode (Range)	P-Value	Effect size ¹
Glut.Ham R	3(2–5)	3(2–5)	4(3–5)	0.37	0.32
Glut. Ham L	3(2–5)	3(2–5)	4(2–5)	0.79	0.07
Hip IR R	3(2–5)	3(2–5)	5(2–5)	0.26	0.33
Hip IR L	3(2–5)	3(2–5)	5(2–5)	0.41	0.28
Hip ER R	3(2–5)	3(2–5)	3(2–5)	0.37	0.28
Hip ER L	3(2–5)	3(2–5)	3(2–5)	0.54	0.23
Hip Abduction R	4(3–5)	4(3–5))	5(3–5)	0.88	0.01
Hip Abduction L	5(3–5)	4(3–5)	5(3–5)	0.79	0.17
Hip Adduction R	5(3–5)	5(3–5)	5(4–5)	0.81	0.19
Hip Adduction L	5(3–5)	5(3–5)	5(4–5)	0.95	0.08
Shoulder IR R	5(3–5)	5(3–5))	5(3–5)	0.23	0.47
Shoulder ER R	5(2–5)	5(2–5)	5(3–5)	0.53	0.14
Shoulder IR L	5(2–5)	5(2–5)	5(3–5)	0.68	0.17
Shoulder ER L	5(2–5)	5(2–5)	5(3–5)	0.23	0.37

DF = Dorsiflexion; PF = Plantar flexion; R = Right; L = Left; F = Flexion; E = Extension; IR = Internal rotation; ER = External Rotation.

¹ Tests with normal distribution – independent *t*-test performed. All other tests non-parametric distribution – Mann-Whitney *U* test performed. The appropriate accompanying effect size (based on the normality of data) was calculated.**Table 3**Logistic regression analysis for tests with bivariate correlations of which $p < 0.20$

	Constant	Coefficient	Standard Error	Wald (Z-value)	P-value	OR	CI
Obliques strength	1.13	0.39	0.70	0.57	0.57	1.04	0.91–1.19
Lateral depth jump - Left	3.90	-0.36	0.04	-0.93	0.35	0.96	0.89–1.04
Lateral depth jump - Right	7.28	-0.075	0.50	-1.51	0.13	0.92	0.84–1.02
Rugby specific fitness test	1.14	1.27	0.72	1.67	0.96	3.32	0.81–13.67

IR = Internal rotation; OR = Odds Ratio; CI = Confidence interval.

Table 4Statistics of association from 2×2 contingency tables for plyometric and rugby specific fitness test (RSFT) and Receiver Operating Characteristic (ROC) for continuous variables.

Test	Sensitivity	Specificity	PPV	NPV	Odds Ratio	OR CI	ROC AUC	SE	CI
Triple horizontal broad jump	0.44	0.75	0.80	0.38	2.40	0.53–10.88	0.50	0.09	0.32–0.68
Static-to-vertical jump	0.22	0.50	0.50	0.22	0.29	0.07–1.22	0.51	0.01	0.31–0.71
Depth jump	0.85	0.42	0.77	0.56	4.11	0.86–19.61	0.47	0.11	0.27–0.68
Lateral Depth Jump Right	0.44	0.75	0.80	0.38	2.40	0.53–10.88	0.36	0.10	0.16–0.57
Lateral Depth Jump Left	0.41	0.83	0.85	0.38	3.44	0.63–18.84	0.45	0.11	0.24–0.66
Counter movement jump	0.11	0.83	0.60	0.29	0.63	0.09–4.33			
Rugby specific fitness test	0.73	0.54	0.76	0.50	3.17	0.79–12.75			

PPV = Positive predictive value; NPV = Negative predictive value; OR = Odds ratio; CI = Confidence interval; ROC = Receiver Operating Characteristic; AUC = Area under the curve; SE = standard error.

(Fuller et al., 2007b), high impact associated with the event and magnitude of torque on joints and soft tissue during a tackle or failed attempt to avoid collision.

4.2. Previous injury

Studies investigating a multitude of injuries and sports, concluded that previous injury history is one of the strongest risk factors for injury with OR of between 2.00 and 6.00 (Arnason et al., 2004; Chalmers et al., 2012; Freckleton & Pizzari, 2013). Consistent with the findings of the above mentioned studies and those reported by Quarrie et al. (Quarrie, 2001a, 2001b), who specifically investigated rugby injury risk factors, this study found that rugby players with a history of injury were 2.63 times more likely to sustain an injury during the current season.

4.3. MSK risk factors to injury

When holistically considering all statistical measures in this study, none yield irrefutable results regarding the association between the individual MSK tests included and injury. Considering that MSK screening tests measure physical performance characteristics, it is not unusual that test results between injured and uninjured groups overlap (Bahr, 2016). Several authors (Nielsen et al., 2020; Verhagen et al., 2018) explain that due to the complex nature of sport injuries, even risk factors truly associated with injury might yield weak results when investigated. Like Bahr (Bahr, 2016), Verhagen (Verhagen et al., 2018) highlights that current analytical strategies cannot sufficiently reflect the unpredictable and multi-factorial nature of sport injuries. This however does not mean that screening has no clinical utility. While the usefulness of individual screening tests are limited, a combination of physical tests remains useful when properly interpreted (Bahr, 2016; Verhagen et al., 2018). Additionally, screening provides an entry point for medical care of players and provides the opportunity for the medical and conditioning staff to establish rapport with players (Bahr, 2016).

4.4. Strength tests

Considering that there were few significant differences between groups and weak associations to injury in terms of strength test outcomes, some might argue that a different manner of testing might be more appropriate. However, Gabbett et al. (Gabbett et al., 2012a, 2012b), included the one repetition maximum (1RM) bench press, 1 RM power clean, squat and weighted chin-up tests and found that only the chin-up test (Hazard ratio = 2.2; 95% CI = 1.3–3.7) had some association to injury. Quarrie et al. (Quarrie, 2001a, 2001b) included the push-up test in their pre-season screening protocols and found no association to injury incidence but some relationship (RR = 2.69–2.19; 95% CI = 0.99–5.84) to the portion of season missed due to injury. Clinical and investigative limitations regarding isokinetic strength testing (with Biodex/Cybox or hand-held dynamometers) have also been discussed in Appendix B (online supplementary material). It therefore seems that regardless the method of strength testing, few studies yield promising results in terms of establishing associations to injury.

4.5. Physical fitness related tests

The associated large 95% CI of the plyometric and RSFT tests' ORs (Table 4) might be contributed to the relatively small sample size within the individual cell of the 2×2 contingency table (Szumilas, 2010). Proposed methods to address large CIs, such as stratification and multiple regression analysis, would however not have been

appropriate considering the sample size (Szumilas, 2010). Nevertheless, considering the OR and the difference in means between injured and non-injured groups discussions of the results are warranted.

4.6. Plyometric tests

With exception of the countermovement jump, the ORs associated with the proposed minimum standards for jumps (lateral depth jump (OR = 2.40–3.44; 95% CI = 0.53–18.84), triple horizontal broad jump (OR = 2.40; 95% CI = 0.53–10.88) and depth jump (OR = 4.11; 95% CI = 0.86–19.61) which are cyclic in nature (i.e., eccentric stretch precedes concentric muscle action resulting in the stretch-reflex), indicated that players who didn't achieve the set score were at least twice as likely to get injured. In contrast, players who didn't achieve the minimum standard for the static-to-vertical jump (OR = 0.29; 95% CI: 0.07–1.22) were four times less likely to incur injuries during the season. This might indicate that players who are used to or trained to utilise the stretch-reflex to generate power and related displacement (and therefore not only forcefully contract agonist muscles concentrically as required by the static-to-vertical jump), might be less likely to incur injury. Sman et al. (Sman et al., 2014) found that rugby players who achieved higher vertical jump (starting from squat position and therefore eliminates the stretch-reflex) heights were also more prone to syndesmosis injuries but contributes this to the competitive nature of players who are also more likely to take greater risks during play.

Gabbett et al. (Gabbett et al., 2012a, 2012b) included the weighted squat jump, countermovement vertical jump (CMVJ) and bench-throw tests in their screening protocol, while Quarrie et al. (Quarrie, 2001a, 2001b) only included the CMVJ test. Neither of the studies found any relation between these tests and injury incidence. Contrary to this study however, none of the jumps' heights were compared to other types of jumps' heights or player height. The formerly mentioned studies therefore didn't explore the relationship between players' strength deficit (Verkhoshansky & Siff, 2009). Verkhoshansky (Verkhoshansky & Siff, 2009) explains that the strength deficit (difference between CMVJ or STVJ height and depth jump height) is an indication of athletes' ability to utilise the stretch-reflex (involuntary effort) to produce power and that lack thereof might not only affect athletic performance but also increase injury risk.

4.7. Rugby specific fitness test

In this study, there was a significant difference (Chi X (Kaplan et al., 2008) = 2.89; $p = 0.09$) in RSFT distance covered by the injured and non-injured groups and players who didn't achieve the position specific standards were three times (OR = 3.17; 95% CI = 0.79–12.75) more prone to injuries. Similarly, Gabbett et al. (Gabbett et al., 2012a, 2012b) found that players with poorly developed prolonged high intensity intermittent running (HIIR) ability were at higher risk (HR = 2.9; 95% CI = 1.7–5.0) of sustaining recurring contact injuries. Numerous studies (Gabbett & Domrow, 2005; Gabbett et al., 2012a, 2012b; Quarrie, 2001a, 2001b) agree that considering the demands of the sport, rugby players require the ability to tolerate a high level of HIIR. These studies highlighted the influence of fatigue on optimal tackling mechanics which ultimately leads to contact injury. Extending this rationale to running and change of direction mechanics might further explain acute, non-contact type injuries.

Verral et al. (Verral, 2005) concluded that increasing the amount of sport specific training drills and high intensity anaerobic interval training, reduced the incidence of hamstring injuries

among rugby league players. Quarrie (Quarrie, 2001a, 2001b) proposed that further investigation is warranted to determine if players who are adequately conditioned for physical impact at the beginning of the season are less likely to sustain in-season injuries. It is therefore plausible to propose that a more rugby specific test (such as the RSFT which requires the execution of tackles i.e., impact during HIIR) compared to a general HIIR test is more appropriate and more closely related to injury risk.

4.8. Strengths and limitations of this study

The screening procedures were performed by a physiotherapist who was experienced in the execution of the tests. Injury surveillance was done by the team's medical staff and therefore not reliant on players' self-reporting or recall. The homogenous population and longitudinal, prospective designs are also strengths of this study.

Considering the limitations posed by small sub-groups, no distinction was made between forward and backline players during analysis. The physical demands and related musculoskeletal adaptations related to specific positions may play a role in the combination of risk factors associated with injury. A larger sample size will allow for this subgroup analysis. The small sample size was also associated with large CI's as well as CI - values that crossed 1, yielding limitations in interpretation of results. A longer surveillance period might also be more representative of the dynamic nature of potential risk factors.

4.9. Clinical and future research considerations

To draw inferences from screening tests, clinicians should consider the results of individual screening tests in the context of the results of multiple other screening tests. Physical tests that are safe yet still reflect the physical impact and demands of the rugby should be included in comprehensive screening protocols.

Research investigating the effect of developing players plyometric ability (which is cyclic in nature) and rugby specific HIIR ability on injury risk should be investigated. Additionally, epidemiological and biostatistical studies should explore analytical methods that could more so account for the multi-faceted and dynamic nature of rugby related risk factors.

5. Conclusion

Rugby union players who achieved the proposed standards for the triple horizontal broad jump, lateral depth jump, vertical depth jumps and SSL® RSFT, are less likely to incur injuries. Future pre-season screening protocols could therefore include these tests to identify rugby players with increased injury risk. Conditioning programmes aimed to develop intermittent high intensity running ability (i.e., anaerobic capacity), whilst executing rugby specific skills, as well as ability to produce power involuntarily using the stretch-reflex, may assist to reduce injury risk in this population.

Ethical statement

Ethical approval was granted from the local tertiary institution's Human Research Ethics Committee (Medical) (M180452). Written informed consent was obtained from the rugby union, the coaches of the respective teams and players who volunteered to participate in the study. All procedures were conducted in accordance with the Declaration of Helsinki.

Declaration of competing interest

Declaration of interest: None.

Appendix. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ptsp.2021.10.002>.

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