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Eccentric Knee Flexor Strength and Risk of Hamstring Injuries in Rugby Union

A Prospective Study

Matthew N. Bourne,* BAppSci, David A. Opar,† PhD, Morgan D. Williams,‡ PhD, and Anthony J. Shield,*§ PhD
Investigation performed at Queensland University of Technology, Brisbane, Australia

Background: Hamstring strain injuries (HSIs) represent the most common cause of lost playing time in rugby union. Eccentric knee flexor weakness and between-limb imbalance in eccentric knee flexor strength are associated with a heightened risk of HSIs in other sports; however, these variables have not been explored in rugby union.

Purpose: To determine if lower levels of eccentric knee flexor strength or greater between-limb imbalance in this parameter during the Nordic hamstring exercise are risk factors for HSIs in rugby union.

Study Design: Cohort study; Level of evidence, 2.

Methods: This prospective study was conducted over the 2014 Super Rugby and Queensland Rugby Union seasons. In total, 178 rugby union players (mean age, 22.6 ± 3.8 years; mean height, 185.0 ± 6.8 cm; mean weight, 96.5 ± 13.1 kg) had their eccentric knee flexor strength assessed using a custom-made device during the preseason. Reports of previous hamstring, quadriceps, groin, calf, and anterior cruciate ligament injuries were also obtained. The main outcome measure was the prospective occurrence of HSIs.

Results: Twenty players suffered at least 1 HSI during the study period. Players with a history of HSIs had a 4.1-fold (95% CI, 1.9-8.9; P = .001) greater risk of subsequent HSIs than players without such a history. Between-limb imbalance in eccentric knee flexor strength of ≥15% and ≥20% increased the risk of HSIs by 2.4-fold (95% CI, 1.1-5.5; P = .033) and 3.4-fold (95% CI, 1.5-7.6; P = .003), respectively. Lower eccentric knee flexor strength and other prior injuries were not associated with an increased risk of future HSIs. Multivariate logistic regression revealed that the risk of reinjuries was augmented in players with strength imbalances.

Conclusion: Previous HSIs and between-limb imbalance in eccentric knee flexor strength were associated with an increased risk of future HSIs in rugby union. These results support the rationale for reducing imbalance, particularly in players who have suffered a prior HSI, to mitigate the risk of future injuries.

Keywords: injury prevention; muscle injuries; Nordic hamstring exercise; physical therapy/rehabilitation; rugby

Rugby union is a physically demanding contact game with one of the highest reported incidences of match injuries of all sports.[7,18,40] The unique nature of the sport exposes athletes of varying anthropometric characteristics[45] to frequent bouts of high-intensity running, kicking, and unprotected collisions, interspersed with periods of lower intensity aerobic work.[14] A hamstring strain injury (HSI) represents the most common cause of lost playing and training time at the professional level,[8,9] and a significant portion of these injuries recur, resulting in extended periods of convalescence.[9]

Despite the prevalence of HSIs in rugby union,[8] efforts to identify risk factors and to optimize injury prevention strategies are limited.[9,36] It is generally agreed that the cause of HSIs is multifactorial,[24] and injuries result from the interaction of several modifiable[10,12,13,21,28,29,33] and nonmodifiable[2,19,20,38] risk factors. In rugby union,[9] as well as several other sports,[3,28,41] HSIs most frequently result from high-

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speed running, which potentially explains why the incidence of HSIs is significantly higher for backline rugby players, who perform longer and more frequent sprints than forwards.[9] During running, the biarticular hamstrings play a crucial role in decelerating the forward swinging shank during terminal swing[44] and in generating horizontal force on ground contact.[23] Given the active lengthening role of the hamstrings, it has been proposed that eccentric weakness[28] or between-limb imbalances in eccentric strength may predispose to HSIs, and both factors have been associated with the risk of HSIs in other sports.[13,15,21,29,42] Furthermore, interventions aimed at improving eccentric strength with the Nordic hamstring exercise reduce the incidence and severity of HSIs in soccer,[1,32] while professional rugby union teams employing the exercise have been reported to suffer fewer HSIs than those that do not.[9] Still, the role of eccentric strength in the occurrence of HSIs remains a controversial issue with contradictory results reported in the literature,[4,46] and a recent meta-analysis suggested that isokinetically derived measures of strength do not represent a risk factor for HSIs.[17] Nevertheless, the authors are not aware of any study that has examined the relationship between eccentric knee flexor strength, between-limb imbalance, and the incidence of HSIs in rugby union. Given the unique anthropometric characteristics of rugby union players[45] and the diverse physical demands of the game,[14,40] it may not be appropriate to generalize the findings from other sports to this cohort.

It has been shown that eccentric knee flexor strength can be reliably measured during the performance of the Nordic hamstring exercise.[26] In a recent prospective study of elite Australian footballers,[28] players with low Nordic strength measures in the preseason training period were significantly more likely to sustain an HSI in the subsequent competitive season. However, it remains to be seen if the same measures can identify rugby union players at risk of future HSIs.

An improved understanding of the risk factors for HSIs in rugby union represents the first step[37] toward optimizing injury prevention strategies and reducing the high rates of HSIs in the sport.[8,9] The aim of this study was to determine whether preseason eccentric knee flexor strength and between-limb imbalance in strength measured during the Nordic hamstring exercise were predictive of future HSIs in rugby union players. In addition, given the multifactorial origin of HSIs[24] and the potential for various risk factors to interact,[34] a secondary aim was to determine the association between measures of eccentric strength, imbalance, and other previously identified risk factors, such as a prior HSI.[9,34] The a priori hypothesis was that subsequently injured players would display lower levels of eccentric knee flexor strength and greater between-limb imbalances in this measure than players who remained free from HSIs.

METHODS

Participants and Study Design

This prospective cohort study was approved by the Queensland University of Technology's Human Research Ethics Committee and was completed during the 2014 Super 15 and Queensland Rugby Union (QRU) seasons. In total, 194 male rugby players (mean age, 22.6 ± 3.8 years; mean height, 185.0 ± 6.7 cm; mean weight, 97.0 ± 13.1 kg) from 3 professional Super 15 clubs (n = 75) and 2 local QRU clubs (n = 119) provided written informed consent to participate. The QRU clubs included players in both subelite (n = 79) and U'19 premier-grade teams (n = 40). Before the commencement of data collection, retrospective injury details were collected for all players, which included their history of hamstring, quadriceps, and calf strain injuries and chronic groin pain within the preceding 12 months as well as a history of anterior cruciate ligament (ACL) injuries at any stage in their career. Demographic (age) and anthropometric (height, body mass) data were also collected in addition to player position (forward, back). For all Super 15 players, these data were obtained from team medical staff and the national Australian Rugby Union registry. All subelite players completed a standard injury history form with their team physical therapist, and injuries were confirmed with information from each club's internal medical reporting system. Subsequently, players had their eccentric knee flexor strength assessed at a single time point within the 2014 preseason (Super 15, November 2013; subelite, January 2014). At the discretion of team medical staff, some players (n = 16) were excluded from strength testing because they had an injury or illness at the time of testing that precluded them from performing maximal resistance exercise.

Eccentric Knee Flexor Strength Assessment

The assessment of eccentric knee flexor strength during the Nordic hamstring exercise has been reported previously.[26,28] Participants knelt on a padded board, with the ankles secured immediately superior to the lateral malleolus by individual ankle braces, which were attached to custom-made uniaxial load cells (Delphi Force Measurement) with wireless data acquisition capabilities (Mantracourt) (Figure 1). The ankle braces and load cells were secured to a pivot, which allowed the force generated by the knee flexors to always be measured through the long axis of the load cells. Immediately before testing, players were provided with a demonstration of the Nordic hamstring exercise from investigators and received the following instructions: gradually lean forward at the slowest possible speed while maximally resisting this movement with both limbs and keeping the trunk and hips in a neutral position throughout, with the hands held across the chest.[28] Subsequently, players completed a single warm-up set of 3 repetitions, followed by 1 set of 3 maximal repetitions of the bilateral Nordic hamstring exercise. All trials were closely monitored by investigators to ensure strict adherence to the proper technique, and players received oral encouragement throughout each repetition to encourage maximal effort. A repetition was deemed acceptable when the force output reached a distinct peak (indicative of maximal eccentric strength), followed by a rapid decline in force, which occurred when the athlete was no longer able to resist the effects of gravity acting on the segment

Figure 1. The Nordic hamstring exercise performed on the testing device (progressing from left to right). Participants were instructed to lower themselves to the ground as slowly as possible by performing a forceful eccentric contraction of their knee flexors. Participants only performed the eccentric portion of the exercise and, after ''catching their fall,'' were instructed to use their arms to push back into the starting position (not shown here). The ankles were secured independently.

above the knee joint. All eccentric strength testing was performed in a rested state before the commencement of scheduled team training.

Data Analysis

Force data for the left and right limbs were transferred to a personal computer at 100 Hz through a wireless USB base station receiver (Mantracourt). Eccentric strength, determined for each leg from the peak force during the best of 3 repetitions of the Nordic hamstring exercise, was reported in absolute terms (N) and relative to body weight ($N \cdot kg^{-1}$). For the uninjured group, between-limb imbalance in peak eccentric knee flexor force was calculated as a left:right limb ratio and, for the injured group, as an uninjured:injured limb ratio. The between-limb imbalance ratio was converted to a percentage difference as per previous work[28] using log-transformed raw data, followed by back transformation.

Reporting of Prospective HSIs

An HSI was defined as acute pain in the posterior thigh that caused an immediate cessation of training or match play and damage to the hamstring muscle-tendon unit,[28] which was later confirmed with magnetic resonance imaging (for all Super 15 players) or clinical examination by the team physical therapist (for all subelite and U'19 players). For all injuries that satisfied the inclusion criteria, team medical staff provided the following details to investigators: limb injured (left/right), muscle injured (long or short head of the biceps femoris/semimembranosus/semitendinosus), injury severity (grade 1-3), injury mechanism (ie, running, kicking, collision, change of direction), date of injury and whether it was a recurrence, and total time taken to resume full training and competition.

Statistical Analysis

All statistical analyses were performed using JMP 10.02 (SAS Institute Inc). Means ± SDs of age, height, weight, eccentric knee flexor strength for the left and right limbs, and between-limb imbalance (%) in strength were determined. Because the player and not the leg was the unit of measure in some analyses, it was necessary to have a single measure of eccentric knee flexor strength for each athlete, and this was determined by averaging the peak forces from each limb (2-limb–average strength). Univariate analysis was used to compare age, height, weight, and between-limb imbalance between the injured and uninjured groups. Eccentric knee flexor strength of the injured limb was compared with the uninjured contralateral limb and to the average of the left and right limbs from the uninjured control group. In addition, eccentric knee flexor strength was compared between elite, subelite, and U'19 players and between player positions (forwards vs backs). All univariate comparisons were made using independent-samples *t* tests with Bonferroni corrections to control for type I errors.

To calculate the univariate relative risk (RR) and 95% CIs, players were grouped according to

- whether they had a history of
  - an HSI in the previous 12 months,
  - a quadriceps strain injury in the previous 12 months,
  - chronic groin pain in the previous 12 months,
  - a calf strain injury in the previous 12 months, or
  - an ACL injury at any stage;
- 2-limb–average eccentric knee flexor strength above or below 267.9 N or 3.18 $N \cdot kg^{-1}$ (these cutoffs were determined using receiver operating characteristic (ROC) curves based on the force and relative force values that maximized the difference between sensitivity and 1 – specificity);
- between-limb imbalance in eccentric strength above or below a 10%, 15%, or 20% cutoff; and
- whether they were above or below the 25th, 50th, and 75th percentiles for age, for height, and for weight.

Any variable associated with subsequent HSIs according to univariate analyses was entered into a univariate logistic regression model to determine its predictive value as a risk factor for future HSIs. Furthermore, given the multifactorial nature of HSIs, a multivariate logistic regression model was constructed (using prior HSIs and between-limb imbalance) to explore the potential interaction between risk factors[28] and eliminate any confounding effects.[30] α was set at $P < .05$, and for all univariate analyses, the difference between limbs and groups is reported as the mean difference and 95% CI.

RESULTS

Details of Cohort and Prospective HSIs

In total, 178 players (mean age, 22.6 ± 3.8 years; mean height, 185.0 ± 6.8 cm; mean weight, 96.5 ± 13.1 kg) had their eccentric knee flexor strength assessed in the preseason period. Of these, 75 were in the elite (mean age, 24.4 ± 3.1 years; mean height, 186.0 ± 7.2 cm; mean weight, 101.0 ± 11.3 kg), 65 were in the subelite (mean age, 21.3 ± 3.7 years; mean height, 184.0 ± 6.4 cm; mean weight, 93.0 ± 13.4 kg), and 38 were in the U'19 division (mean age, 18.1 ± 0.8 years; mean height, 183.0 ± 6.8 cm; mean weight, 91.0 ± 14.9 kg).

Twenty athletes suffered at least 1 HSI during the 2014 competitive season (mean age, 22.5 ± 3.0 years; mean height, 185.8 ± 5.5 cm; mean weight, 97.4 ± 12.4 kg), and 158 remained free of HSIs (mean age, 22.3 ± 3.6 years; mean height, 184.9 ± 7.0 cm; mean weight, 96.4 ± 13.3 kg). No significant differences were observed in terms of age, height, or body mass between the subsequently injured and uninjured players ($P > .05$). HSIs resulted in a mean of 21 days' (range, 7-49 days) absence from full training and match play. Forty-five percent were recurrences from the previous season, and 25% of those observed in the 2014 observation period recurred later in the same season. Of the 20 injuries, 80% affected the biceps femoris as the primary site of injury, and 85% resulted from high-speed running. The majority of HSIs were sustained by backs (60%) compared with forwards (40%). No injuries were sustained during the assessment of eccentric knee flexor strength.

Comparison of Strength Between Playing Level and Position

Eccentric strength measures for each level of play and player position can be found in Table 1. In terms of eccentric strength, there was no significant difference between elite and subelite players (mean difference, 21.0 N [95% CI, –7.8 to 49.9]; P = .154) or between elite and U'19 players (mean difference, 24.1 N [95% CI, –6.90 to 55.0]; P = .126); however, subelite players were significantly stronger than U'19 players (mean difference, 45.1 N [95% CI, 8.1 to 82.0]; P = .017). When expressed relative to body weight, both subelite (mean difference, 0.35 N·kg^{-1} [95% CI, 0.08 to 0.63]; P = .013) and U'19 players (mean difference, 0.38 N·kg^{-1} [95% CI, 0.07 to 0.70]; P = .017) were significantly stronger than elite players, although no difference was observed between subelite and U'19 players (mean difference, –0.03 N·kg^{-1} [95% CI, –0.4 to 0.34]; P = .870). In absolute terms, forward line players were significantly stronger than backs (mean difference, 35.4 N [95% CI, 10.11 to 60.5]; P = .006); however, no difference was observed when strength was normalized to body weight (mean difference, –0.1 N·kg^{-1} [95% CI, –0.35 to 0.16]; P = .583).

TABLE 1
Preseason Nordic Hamstring Exercise Force Variables for Each Level of Competition and Player Position[a]

Playing Group	Absolute Eccentric Knee Flexor Strength, N	Relative Eccentric Knee Flexor Strength, N·kg^{-1}
Elite (n = 75)	366.9 ± 76.9	3.65 ± 0.71[d]
Subelite (n = 65)	387.9 ± 96.3[b]	4.00 ± 0.93
U'19 (n = 38)	342.8 ± 81.5[b]	4.03 ± 0.92
Forward (n = 82)	388.5 ± 95.5[c]	3.81 ± 0.92
Back (n = 96)	353.1 ± 74.9[c]	3.90 ± 0.80

[a]Data are presented as mean ± SD.
[b]Significant difference between subelite and U'19 groups.
[c]Significant difference between back and forward groups.
[d]Significantly different from both the U'19 and subelite groups.

Univariate Analysis of Factors Associated With HSIs

Eccentric knee flexor strength and between-limb imbalances for the injured and uninjured groups can be found in Table 2. Limbs that went on to be injured were significantly weaker in the preseason than uninjured contralateral limbs both in absolute terms (mean difference, 55.0 N [95% CI, 11.65-98.5]; P = .016) and when normalized to body mass (mean difference, 0.56 N·kg^{-1} [95% CI, 0.13-0.98]; P = .013). Players who went on to sustain an HSI displayed higher levels of between-limb imbalance than those players who remained free from HSIs (mean difference, 7.4% [95% CI, 2.4 to 12.4]; P = .004). However, there was no difference between the subsequently injured limb and the average of the left and right limbs from the uninjured group either in absolute strength (mean difference, 12.7 N [95% CI, –27.0 to 52.2]; P = .529) or strength relative to body mass (mean difference, 0.2 N·kg^{-1} [95% CI, –0.20 to 0.60]; P = .321). No significant differences were observed in age (mean difference, 0.18 years [95% CI, –1.5 to 1.9]; P = .829), height (mean difference, 0.86 cm [95% CI, –2.3 to 4.1]; P = .597), or weight (mean difference, 0.97 kg [95% CI, –5.2 to 7.4]; P = .757) between the injured and uninjured groups.

Relative Risk

Players with a history of HSIs in the previous 12 months had a 4.1 (95% CI, 1.9-8.9; P = .001) times greater risk of suffering a subsequent HSI than players with no HSIs in the same period (Table 3). Between-limb imbalance in eccentric knee flexor strength of ≥15% increased the risk of HSIs 2.4-fold (95% CI, 1.1-5.5; P = .033), while an imbalance of ≥20% increased that risk 3.4-fold (95% CI, 1.5-7.6; P = .003). However, players with 2-limb–average eccentric

TABLE 2
Preseason Nordic Hamstring Exercise Force Variables for Injured and Uninjured Rugby Union Players[a]

Group	Absolute Eccentric Knee Flexor Strength, N	Relative Eccentric Knee Flexor Strength, N·kg^{-1}	Between-limb Imbalance, %
Injured			17.37 ± 16.1[c]
Injured limb (n = 20)	355.1 ± 80.5[b]	3.65 ± 0.67[b]	
Uninjured limb (n = 20)	410.1 ± 132.4[b]	4.21 ± 1.14[b]	
Uninjured			
Average of left and right limbs (n = 158)	367.7 ± 85.0	3.85 ± 0.87	10.02 ± 9.8[c]

[a]Data are presented as mean ± SD.
[b]Significant difference between limbs in the injured group ($P < .05$).
[c]Significant difference between injured and uninjured players.

knee flexor strength of less than 267.9 N were not at an elevated risk of HSIs (RR, 0.17 [95% CI, 0.0-2.7]; $P = .204$) compared with stronger players (area under the ROC curve, 0.52; specificity, 0.86; sensitivity, 1.0). Similarly, having a normalized strength value of less than 3.18 N·kg^{-1} did not increase the risk of HSIs (RR, 0.97 [95% CI, 0.3-2.7]; $P = .957$).

Logistic Regression

Players with a history of HSIs in the previous 12 months were, according to the odds ratio, 5.30 times more likely (95% CI, 1.84-15.00; $P = .003$) to suffer a subsequent HSI than players who had remained injury free in that time. In addition, a relationship was observed between the magnitude of between-limb imbalance in eccentric knee flexor strength and the risk of subsequent HSIs in which for every 10% increase in between-limb imbalance, the odds of HSIs increased by a factor of 1.34 (95% CI, 1.03-1.75; $P = .028$) (Figure 2).

Multivariate logistic regression revealed a significant ($P < .001$) relationship between both prior HSIs and between-limb imbalance and the risk of subsequent HSIs (Table 4); however, no interaction effect was observed between these variables. This model suggests that for players with a history of HSIs, the risk of reinjuries is amplified when they also have between-limb imbalances in eccentric knee flexor strength (Figure 2).

DISCUSSION

The aim of this study was to determine if rugby union players with lower levels of eccentric strength or larger between-limb imbalances in this measure, as determined during the Nordic hamstring exercise, were at an increased risk of HSIs. Higher levels of between-limb imbalance were found to significantly increase the risk of subsequent HSIs, and this was amplified in athletes who had suffered the same injury in the previous 12 months. However, while the limbs that went on to be injured were significantly weaker than the uninjured contralateral limbs in preseason testing, weaker players were no more likely to suffer an injury than stronger players when strength was determined by averaging the peak eccentric forces from the left and right limbs.

The observation that higher levels of between-limb strength imbalance increase an athlete's risk of HSIs is consistent with previous reports.[13,15,21,29,42] Croisier and colleagues[13] reported that professional soccer players with isokinetically derived knee flexor strength imbalances in the preseason had a 4.66-fold greater risk of subsequent HSIs than athletes without such imbalances. More recently, Fousekis and colleagues[15] found that elite soccer players with imbalances in eccentric knee flexor strength of ≥15% in the preseason had a significantly greater (odds ratio, 3.88) risk of HSIs than athletes with no asymmetry. Still, contradictory results have been reported in Australian footballers,[4,28] and it remains unclear as to the exact mechanism(s) by which significant imbalances increase the risk of HSIs. It is plausible that between-limb imbalances in eccentric knee flexor strength may alter running biomechanics[11] or reduce the capacity of the weaker limb to decelerate the forward swinging shank during terminal swing.[25] However, it should also be noted that the assessment of between-limb imbalance in the current study was performed during a bilateral Nordic hamstring exercise, whereas typical assessments involve maximal unilateral contractions performed on an isokinetic dynamometer.[4,15] For this reason, direct comparisons to previous work should be made with caution. A bilateral Nordic hamstring exercise was employed in the current study as previous work has shown that this is a more reliable test of eccentric knee flexor strength than a unilateral Nordic exercise.[26]

The finding that weaker players were no more likely to sustain an HSI than stronger players is in line with a recent systematic review and meta-analysis that suggested isokinetically derived measures of strength were not a risk factor for HSIs in sport.[17] However, the results of the current study differ from those of a recent investigation[28] using the Nordic hamstring test that reported elite Australian footballers with eccentric strength of <256 N at the start of the preseason and <279 N at the end of the preseason had a 2.7- and 4.3-fold greater risk of HSIs, respectively. The disparity between studies might reflect the vastly different anthropometric characteristics of rugby union[45] and Australian football players[5] or the unique physical demands of each sport.[14,31] However, it

TABLE 3
Univariate Relative Risk of Suffering a Future HSI[a]

Risk Factor	n	% of Each Group That Sustained an HSI	Relative Risk (95% CI)	*P* Value
Prior injury				
HSI	30	30.0	4.10 (1.9-8.9)	.001[b]
No HSI	164	7.3	0.24 (0.1-0.5)	
ACL	16	12.5	1.17 (0.3-4.6)	.538
No ACL	178	10.7	0.85 (0.2-3.3)	
Calf strain	6	14.3	1.33 (0.2-8.5)	.560
No calf strain	188	10.8	0.75 (0.1-4.8)	
Quadriceps strain	10	10.0	0.92 (0.1-6.2)	.691
No quadriceps strain	184	10.9	1.09 (0.2-7.3)	
Chronic groin pain	12	8.3	0.76 (0.1-5.2)	.758
No chronic groin pain	182	11.0	1.32 (0.2-9.0)	
Preseason eccentric hamstring strength				
<267.9 N	22	0	0.17 (0.0-2.7)	.204
≥267.9 N	156	12.8	6.00 (0.4-96.0)	
<3.18 $N\cdot kg^{-1}$	36	11.1	0.97 (0.3-2.7)	.957
≥3.18 $N\cdot kg^{-1}$	140	11.4	1.03 (0.4-2.9)	
Preseason between-limb imbalance				
<10%	113	9.7	0.70 (0.3-1.6)	.403
≥10%	65	13.8	1.42 (0.6-3.3)	
<15%	133	8.3	0.41 (0.2-0.9)	.033[b]
≥15%	45	20.0	2.42 (1.1-5.5)	
<20%	149	8.1	0.29 (0.1-0.7)	.003[b]
≥20%	29	27.6	3.43 (1.5-7.6)	
Age, y				
≤19	48	6.2	0.60 (0.2-2.0)	.397
>19	146	11.6	1.67 (0.5-5.5)	
≤22	95	10.2	1.04 (0.4-2.2)	.922
>22	99	10.1	0.96 (0.5-2.5)	
≤25	149	10.7	1.20 (0.4-3.4)	.723
>25	45	8.9	0.83 (0.3-2.4)	
Height, cm				
≤180	57	7.0	0.56 (0.2-1.6)	.273
>180	135	12.6	1.79 (0.6-5.1)	
≤185	113	9.7	0.77 (0.3-1.7)	.523
>185	79	12.7	1.30 (0.6-2.9)	
≤189	148	10.1	0.74 (0.3-1.8)	.511
>189	44	13.6	1.30 (0.5-3.3)	
Weight, kg				
≤87	48	6.3	0.50 (1.5-1.6)	.249
>87	144	12.5	2.00 (0.6-6.5)	
≤96.45	95	10.5	1.00 (0.5-2.2)	.979
>96.45	97	11.3	0.99 (0.5-2.2)	
≤105.25	143	11.2	1.10 (0.4-2.8)	.849
>105.25	49	10.2	0.91 (0.4-2.4)	

[a]Using eccentric strength and between-limb imbalance, injury history, and demographic data as risk factors. Height and weight values are for 192 participants, due to missing anthropometric data for 2 participants. ACL, anterior cruciate ligament; HSI, hamstring strain injury.
[b]Significant difference ($P < .05$) in the relative risk of future HSIs between groups.

is also important to consider that the rugby players in the current study were substantially stronger than the Australian footballers studied previously.[28] It is possible that the protective benefits conferred by greater levels of eccentric strength may plateau at higher ends of the strength spectrum as they appear to in Australian footballers (see Figures 1 and 2 in Opar et al[28]). It should also be acknowledged that while some studies have found an association between low levels of knee flexor strength and subsequent HSIs,[21,28,42] a prior injury is also associated with knee flexor weakness,[12,22,26,27,35] and this may confound results.[30]

The current study supports a prior HSI as a risk factor for reinjuries, which is consistent with earlier observations in rugby union,[9,36] Australian football,[4,16,30,39] and soccer.[2] While the mechanism(s) explaining why a prior HSI augments the risk of reinjuries remain(s) unclear, this study revealed a significant relationship between prior HSIs

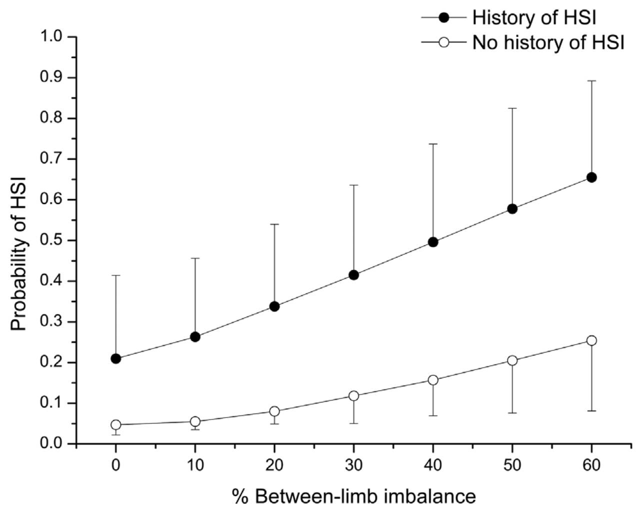

Figure 2. The relationship between eccentric knee flexor strength imbalances and the probability of future hamstring strain injuries (HSIs) for players with and without a history of HSIs in the previous 12 months. Errors bars depict 95% CIs.

and between-limb imbalance in eccentric knee flexor strength. This novel finding suggests that rugby union players with a history of HSIs have a significantly greater risk of reinjuries if they return to training and match play with one limb weaker than the other (Figure 2). For example, an athlete with a prior HSI and a 30% between-limb imbalance in eccentric strength is twice as likely to suffer a recurrence as a previously injured athlete with no imbalance. In light of this interaction, there is a growing body of evidence to suggest that between-limb imbalance in knee flexor strength[12,13,22,29] is a risk factor for the recurrence of HSIs. These data highlight the multifactorial nature of HSIs and suggest that the amelioration of between-limb imbalances in eccentric knee flexor strength should be a focus of rehabilitative strategies after HSIs.

There are some limitations that should be acknowledged in the current study. First, the assessment of eccentric knee flexor strength and between-limb imbalance was only performed at a single time point in the preseason period. While this is consistent with other prospective studies exploring the effect of strength variables on the risk of HSIs,[13,15,21,29,42] it is important to consider that strength may change over the preseason and in-season periods.[28] The assessment of strength at multiple time points may provide a more robust measure of player risk; however, the geographic diversity of the Super 15 competition precluded follow-up assessments by the investigators. Eccentric strength was measured as a force output (N) rather than a joint torque (N·m), which makes a direct comparison to isokinetically derived measures difficult. Further, this mode of testing does not allow for an assessment of the angle at which the knee flexors produce maximum torque[6] and did not permit force to be expressed relative to quadriceps[13] or hip flexor[43] strength, which

TABLE 4
Multivariate Logistic Regression Model[a]

	χ^2	*P* Value	AUC	Sensitivity	1 – Specificity
Whole model	16.00	<.001	0.69	0.6	0.21
Prior HSI	9.33	.002			
Between-limb imbalance, %	4.71	.030			

[a]Using prior HSIs and between-limb imbalance in eccentric knee flexor strength as input variables. AUC, area under the curve; HSI, hamstring strain injury.

may provide additional information on an athlete's risk of HSIs. Finally, the lack of player exposure data prevents HSI rates from being expressed relative to the amount of training and match play. Future work should seek to clarify the effect of total exposure time (particularly to high-speed running) on the incidence of HSIs in rugby union players.[9]

In conclusion, this study suggests that both between-limb imbalances in eccentric knee flexor strength and prior HSIs are associated with an increased risk of future HSIs in rugby union. However, lower levels of eccentric knee flexor strength and a recent history of other lower limb injuries do not significantly increase the risk of future HSIs in this cohort. This study, along with previous findings,[28] highlights the multifactorial nature of HSIs and supports the rationale for reducing imbalance, particularly in players who have suffered a prior injury within the previous 12 months.

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