MARTIN ASKER, DN, PhD[1,2] • **MARKUS WALDÉN,** MD, PhD[3-5] • **HENRIK KÄLLBERG,** PhD[6]
LENA W. HOLM, PhD[1] • **EVA SKILLGATE,** DN, PhD[1,2,7]

Preseason Clinical Shoulder Test Results and Shoulder Injury Rate in Adolescent Elite Handball Players: A Prospective Study

The burden of shoulder injuries is high among senior and adolescent handball players, regardless of sex.[1,2,4,7,8,20,23,24] The average weekly prevalence of substantial shoulder problems is 6% to 12%.[2,4,7,8] Two thirds of adolescent players have reported shoulder problems for more than 1 season.[4]

OBJECTIVE: To investigate whether adolescent elite female and male handball players with shoulder muscle weakness, deficits in shoulder rotation range of motion (ROM) or in joint position sense (JPS), or scapular dyskinesis in the preseason had a higher rate of new shoulder injuries compared to players without these characteristics.

DESIGN: Prospective cohort study.

METHODS: We studied 344 uninjured players (452 player-seasons, 50% female). We measured their shoulder strength in isometric external rotation (IER), isometric internal rotation (IIR), isometric abduction, and eccentric external rotation, as well as their shoulder ROM, JPS, and scapular dyskinesis, during the preseason. Players were monitored weekly regarding match and training hours and shoulder injuries during 1 or 2 seasons. We used multivariable Cox proportional hazard models to calculate hazard rate ratios related to the first injury and 95% confidence intervals (CIs).

RESULTS: During 2 seasons, the participants reported 48 new shoulder injuries. In female players, the hazard rate ratio was 2.37 (95% CI: 1.03, 5.44) for IER weakness and 2.44 (95% CI: 1.06, 5.61) for IIR weakness. The hazard rate ratio was 0.85 (95% CI: 0.39, 1.83) for an IER/IIR ratio of less than 0.75 and 1.53 (95% CI: 0.36, 6.52) for scapular dyskinesis. In male players, the hazard rate ratio was 1.02 (95% CI: 0.44, 2.36) for IER weakness, 0.74 (95% CI: 0.31, 1.75) for IIR weakness, 2.0 (95% CI: 0.68, 5.92) for an IER/IIR ratio of less than 0.75, and 3.43 (95% CI: 1.49, 7.92) for scapular dyskinesis. There were no associations between new shoulder injuries and deficits in ROM or JPS.

CONCLUSION: In adolescent elite handball, male players with preseason scapular dyskinesis and female players with preseason IIR or IER shoulder weakness had an increased shoulder injury rate. *J Orthop Sports Phys Ther 2020;50(2):67-74. Epub 27 Nov 2019. doi:10.2519/jospt.2020.9044*

KEY WORDS: *clinical tests, motion deficits, scapular dyskinesis, youth sports*

Factors such as shoulder weakness, shoulder rotation range of motion (ROM) deficits, scapular dyskinesis, and rapid spikes in training load may increase the risk of shoulder injuries in handball players.[1,7,14,18,23] Rapid increase in handball training load was a risk factor for shoulder injuries in Danish youth handball players. Players who increased their handball training load by 60% or more had double the risk of shoulder injury.[23] Players with shoulder external rotation weakness or scapular dyskinesis, measured at baseline, had a higher risk of shoulder injury with increases in handball training load of as little as 20%.[23] French adolescent female players with shoulder external rotation weakness had a higher risk of shoulder injury.[14] German youth players with shoulder external rotation weakness had a higher risk of overuse shoulder injury.[1] French senior male handball players with shoulder internal rotation weakness had a higher risk of traumatic shoulder injuries.[18] Norwegian senior male players with scapular dyskinesis, shoulder external rotation weakness, or lack of total ro-

[1]Musculoskeletal and Sports Injury Epidemiology Center, Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden. [2]Scandinavian College of Naprapathic Manual Medicine, Stockholm, Sweden. [3]Football Research Group, Linköping University, Linköping, Sweden. [4]Division of Community Medicine, Department of Medical and Health Sciences, Linköping University, Linköping, Sweden. [5]Department of Orthopaedics, Hässleholm-Kristianstad-Ystad Hospitals, Hässleholm, Sweden. [6]Department of Monitoring and Evaluation, Public Health Agency of Sweden, Solna, Sweden. [7]Department for Health Promoting Science, Sophiahemmet University, Stockholm, Sweden. The Regional Ethics Review Board of the Karolinska Institutet approved this study (2013/1722-31/4, 2015/1396-32/4). This study received financial support from the Swedish National Centre for Research in Sports, the Folksam Insurance Company, and the Swedish Naprapathic Association. None of these entities were involved in the design of the study, data collection, data analysis, interpretation of the data, or writing the manuscript. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Martin Asker, Musculoskeletal and Sports Injury Epidemiology Center, Institute of Environmental Medicine, Karolinska Institutet, Box 210, SE-171 77, Stockholm, Sweden. E-mail: martin.asker@ki.se

tation ROM were more likely to sustain a shoulder injury.[7] In a more recent study of Norwegian handball players, increased internal rotation ROM was associated with a higher risk of shoulder injury.[2]

Despite a growing number of studies investigating the association between clinical shoulder tests and the risk of shoulder injury in handball, studies of adolescent elite players are scarce.[3] The burden of shoulder problems in this group is high.[4] Players with persistent problems might not reach their full athletic potential or might quit their sport due to injuries. Consequently, prospective studies investigating the relationship between preseason shoulder characteristics and shoulder injury in adolescent handball players are warranted. We aimed to investigate whether adolescent female and male elite handball players with shoulder muscle weakness, deficits in ROM or joint position sense, or scapular dyskinesis, had a higher rate of new shoulder injuries compared with players who did not have these characteristics.

METHODS

Data included in our study are from the Karolinska Handball Study (KHAST). Details about the study design, methodology, and population are reported elsewhere[5] and will be briefly described.

Population

Students aged 15 to 19 years in 10 of the 38 handball-profiled secondary schools in Sweden were included in the main cohort of the KHAST study (n = 471 female and male players, 622 player-seasons) (**FIGURE**). We followed the included players prospectively during 1 (n = 321) or 2 (n = 150) seasons (2014-2015 and 2015-2016). In those followed for 2 seasons, new preseason data were collected during the second season. In the present study, not all players in the main KHAST cohort were included. To study shoulder injury incidence, we included only players who reported a score of less than 40 on the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire (described below) for the dominant shoulder for the past 2 months and had no difficulties performing the baseline measures (**FIGURE**).

Outcome Measures

The primary outcome was first incidence of shoulder injury in the dominant arm that occurred during a handball match or training session, regardless of traumatic or overuse etiology. The OSTRC Overuse Injury Questionnaire has a total score between 0 and 100.[9] We defined shoulder injury as a score of 40 or more on the OSTRC Overuse Injury Questionnaire for the dominant shoulder at some point during the season.

Exposures

The exposures investigated were shoulder strength, shoulder ROM, scapular dyskinesis, and shoulder joint position sense. Measures of shoulder strength included isometric external rotation, isometric internal rotation, eccentric external rotation, and isometric abduction. Measures of ROM included glenohumeral internal rotation, external rotation, and total ROM.

Confounding

Factors that we considered to be potential confounders, based on studies of potential risk factors, were chosen a priori. We measured potential confounders at baseline, including playing position, school grade, school, and playing level. However, the number of events limited the possibility to include several confounders in the same model. Hence, we included only 1 factor (playing position) in our adjusted model. We included playing position based on our recent study that found playing position to be associated with shoulder problems in adolescent handball players.[4]

Baseline Questionnaire

At inclusion, all players completed a questionnaire (including questions from Fahlström and Söderman[16] and Fahlström et al[17]) about history of shoulder problems and shoulder function, demographic information (including sex, handball experience, playing position, and level of play[5]), and a modified version of the OSTRC Overuse Injury Questionnaire.[9,15] The OSTRC Overuse Injury Questionnaire was modified to collect information about shoulder problems during the past 2 months and the past season (the original questionnaire focuses on shoulder problems during the past week).

Baseline Shoulder Measurement

All players were assessed at baseline (September 2014 and/or September

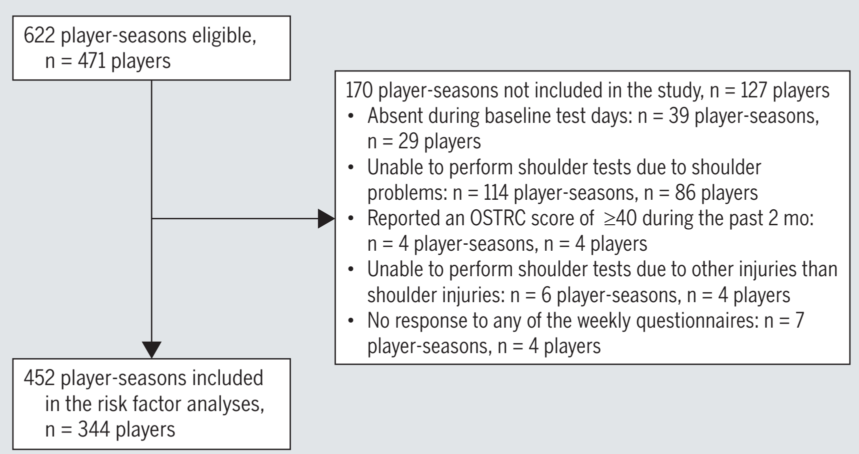

FIGURE. The flow of the study participants and the study population. Abbreviation: OSTRC, Oslo Sports Trauma Research Center.

2015).[5] We measured shoulder strength with a handheld dynamometer (microFET2; Hoggan Scientific, Salt Lake City, UT). Isometric external rotation, isometric internal rotation, and eccentric external rotation shoulder strength was measured in both shoulders with the participant in a seated position.[10,11] Isometric abduction strength was measured in both shoulders with the participant in a standing position and the arm at 30° of abduction in the scapular plane.[7] Each test was performed twice, and the highest recorded value was used in the analysis.

We measured shoulder ROM in both shoulders with the player in supine.[10] One tester fixed the scapula with one hand and performed passive internal rotation of the humerus until movement of the scapula was felt with the other hand. In this position, a second tester measured internal rotation using a digital inclinometer. Passive external rotation of the humerus was measured in the same way.

We measured shoulder joint position sense in the dominant shoulder with the player blindfolded and in supine. The tester externally rotated the arm to a position of 75% of maximum external rotation (the "target angle") and instructed the player to hold that position, without support from the tester, for 3 seconds, after which the tester passively returned the arm to the starting position. The player was then instructed to actively rotate the arm back to the target angle. The tester measured the angle and recorded the difference from the target angle (joint position sense error). The measurement was repeated 3 times, and the mean value of the joint position sense error was used for analysis. We measured joint position sense in external rotation with a target angle of 75% of maximum external rotation because many players in our pilot study reported shoulder pain or soreness when actively externally rotating their shoulder to 90% of their maximum external rotation ROM. We measured joint position sense in a supine position instead of in standing,[12] because we assessed maximum external rotation ROM in supine.

We measured scapular dyskinesis in both shoulders during active glenohumeral abduction and flexion. We used a headlamp to standardize the light setting for each test environment. The test was video-recorded from a posterior view (standardized distance of 3 m). Each player stood and performed 2 repetitions of maximum shoulder abduction and 2 repetitions of maximum shoulder flexion, in random order and with weights. Female players held a 1-kg dumbbell and male players held a 2-kg dumbbell. One tester later observed all videos and judged scapular dyskinesis as present or absent.[29] Separate judgments of scapular dyskinesis were made for abduction and flexion.

Reliability

The same tester or pair of testers performed each test throughout baseline data collection (except for shoulder ROM and joint position sense, for which 2 of the testers were replaced for the 2015-2016 season). All testers were experienced with the test procedure. Before data collection started, all testers performed practice runs of the complete test protocol.

Because every measure was performed either twice (strength and ROM) or 3 times (joint position sense), these values were used to calculate the intrarater reliability of each measure and for each tester. To assess the intra-agreement of scapular dyskinesis, data from the first 43 players were used. The tester reviewed each video in random order and repeated the same procedure 1 week later.

Weekly Monitoring of Shoulder Injuries and Handball Exposure

Players were monitored weekly during the competition season (September to April) during 1 or 2 seasons (2014-2015 and/or 2015-2016). Shoulder injuries, traumatic injuries, and match and training exposure were registered using a questionnaire based on the OSTRC Overuse Injury Questionnaire (**APPENDIX A**, available at www.jospt.org). We added an answer option to the first question in the original questionnaire (0, "Reduced participation/cannot participate due to other reasons than shoulder problem") to minimize any uncertainties for players who could not fully participate due to other reasons than shoulder problems.

Players received an e-mail with a link to the questionnaire every Sunday morning. If the players did not respond, they received a reminder e-mail the day after and a cell phone text message reminder 3 days after the initial e-mail. If players also failed to respond to this text message within 2 days, a research assistant contacted them by telephone and asked for their response. The survey software prevented incomplete reports by not allowing completion if 1 or more responses were omitted.

Statistical Methods

Intraclass correlation coefficients (ICCs) with corresponding 95% confidence intervals (CIs) were calculated to assess the relative reliability of the shoulder tests. To assess intrarater reliability, both of the shoulder strength and ROM measurements were used to calculate the $ICC_{3,1}$ (2-way random model, absolute agreement). Because 3 trials were used to measure joint position sense, only the last 2 trials were used to calculate the ICC. The standard error of measurement was calculated as $SD \times \sqrt{1 - ICC}$. The reliability of the scapular dyskinesis classification was assessed by calculating the Cohen kappa, its 95% CI, and the percentage of agreement.

Injury incidence was calculated as the numbers of injuries divided by 1000 hours of matches/training sessions. We built multivariable Cox proportional hazard models, 1 for each exposure, to compute hazard rate ratios and 95% CIs for the association between the exposures and the event of the first injury (**TABLE 1**). Time at risk was the number of hours of handball matches plus handball training sessions on the handball court between baseline and the first injury to the dominant shoulder. Players who reported a shoulder injury or chose to quit the study were censored. Players who reported other reasons for not fully participating in handball (eg, school breaks, other school commitments, other injuries or illnesses) were not censored, because time at risk was based on the number of hours exposed to handball, not on calendar time. Players who did not respond to any weekly report were excluded from all analyses (**FIGURE**).

Our modeling strategy included 2 steps. First, we performed crude analyses, 1 model for each exposure. Second, we adjusted for playing position. The proportional hazard assumption (eg, that the multiplicative effect of the hazard function is constant over time) was fulfilled for each model.

Ethics Approval

Approval was obtained from the Regional Ethics Review Board of the Karolinska Institutet (2013/1722-31/4, 2015/1396-32/4). All participating players and legal guardians gave written informed consent before entering the study.

TABLE 1 POTENTIAL RISK FACTORS FOR SHOULDER INJURIES IN THE DOMINANT ARM[a]

	Value
Strength normalized to body weight, N/kg	
Isometric external rotation	
Female	1.45
Male	1.57
Isometric internal rotation	
Female	1.87
Male	2.27
Eccentric external rotation	
Female	1.72
Male	1.87
Isometric abduction	
Female	1.31
Male	1.52
Ratio between isometric external rotation and isometric internal rotation	<0.75
Ratio between eccentric external rotation and isometric internal rotation	<0.75
Range of motion, deg	
Internal rotation	
Female	45.00
Male	39.75
External rotation	
Female	101.00
Male	100.00
Total (sum score of internal rotation plus external rotation)	
Female	147.50
Male	139.50
Difference in total range of motion (dominant versus nondominant shoulder)	
Female	1.00
Male	0.00
Scapular dyskinesis, yes/no	
Dominant shoulder during flexion	...
Dominant shoulder during abduction	...
Joint position sense, deg	
Mean error measurement from target angle	
Female	6.33
Male	5.70

[a]*Values are median unless otherwise indicated. Strength, range of motion, and joint position sense were dichotomized by median values. Scapular dyskinesis was dichotomized by answers of yes or no.*

RESULTS

OUT OF THE TOTAL 471 PLAYERS (622 player-seasons), 344 players (452 player-seasons) were classified as shoulder-healthy players at baseline and included in the risk analysis (**TABLE 2**). Eighteen players (5%) dropped out of the study, mainly due to leaving the handball-profiled secondary school.

The average weekly response rate was 92% (95% CI: 91%, 94%), with 345 of 452 player-seasons (76%) reporting complete data. The total time at risk was 31 416 hours in male players and 28 089 hours in female players.

Forty-eight new shoulder injuries were reported in the dominant arm (26 in female players and 22 in male players), of which 42 (88%) were nontraumatic. The incidence of shoulder injuries in the dominant arm was 0.70/1000 hours (95% CI: 0.53, 0.84) in male players and 0.93/1000 hours (95% CI: 0.76, 0.99) in female players.

Reliability

For the strength tests, ICCs ranged from 0.91 to 0.96; for the ROM tests, ICCs ranged from 0.83 to 0.97; and for the joint position sense test, ICCs ranged from 0.68 to 0.95. Cohen's kappa values for scapular dyskinesis ranged from 0.85 to 0.92. The ICCs with corresponding 95% CI and standard error of measurement, and Cohen's kappa values with corresponding 95% CI and percentage of agreement, are presented in **APPENDIX B** (available at www.jospt.org).

Risk Analysis

The hazard rate ratios of shoulder injuries for the different preseason clinical shoulder tests are presented in **TABLE 3**. The hazard rate ratio for isometric external rotation strength was 2.37 (95% CI: 1.03, 5.44) in female players and 1.02 (95% CI: 0.44, 2.36) in male players. The hazard rate ratio for isometric internal rotation strength was 2.44 (95% CI: 1.06, 5.61) in female players and 0.74 (95% CI: 0.31, 1.75) in male players. There was no association between ROM and shoulder injuries for female or male players. The hazard rate ratio for scapular dyskinesis during abduction was 1.53 (95% CI: 0.36, 6.52) in female players and 3.43 (95% CI: 1.49, 7.92) in male players. There was no association between scapular dyskinesis observed during flexion and shoulder injuries for female or male players. There was no association between joint position sense and shoulder injuries in female or male players.

DISCUSSION

We prospectively studied the association between the result of preseason shoulder function measures and the incidence of shoulder injuries separately for elite adolescent female and male handball players. Female players entering the competitive season with weakness in shoulder isometric external rotation strength and isometric internal rotation strength had a higher risk of shoulder injury, and male players entering the competitive season with scapular dyskinesis during abduction had a higher risk of shoulder injury.

Injury Definition

We measured injury using the OSTRC Overuse Injury Questionnaire, and used a cutoff score of 40 or more on the questionnaire to define injury. This cutoff has been used in previous studies of handball players, even though in these studies an average weekly score was used.[2,7] Another definition based on the same questionnaire is "shoulder problems" or "substantial shoulder problems," being based on the specific answers to questions about reduction in participation or performance. We selected the former definition because it included the dimension of pain. Using a composite score instead of a specific answer to a question reduces the risk of misclassification of the outcome when the player incorrectly answers questions about reduction in participation or performance.

Relationship Between Strength and Shoulder Injuries

We found a clear association between isometric external rotation and isometric internal rotation weakness and the risk of shoulder injuries in the female players, but not in the male players. Impaired shoulder strength may be a risk factor for shoulder injuries.[1,7,14,18,23] External rotation weakness was associated with shoulder injuries in French adolescent female players, which supports our results.[14] External rotation weakness was associated with shoulder injuries in German youth players, but direct comparison to our results is difficult because not all analyses were stratified by sex.[1] External rotation weakness was an effect modifier on handball load in Danish adolescent handball players, but the analysis was not stratified by sex.[23] Therefore, it is difficult to directly compare these data to our results. Biomechanics may explain why shoulder weakness was a risk factor in female players but not in male players. Female players may throw with a technique that puts a greater demand on the shoulder, especially rotational strength, compared to male players.[28] However, these findings are inconsistent,[31] and studies of sex differences in throwing biomechanics in adolescent players are scarce.

Relationship Between Shoulder ROM and Shoulder Injuries

We did not find an association between shoulder ROM and shoulder injuries in either male or female players, which

TABLE 2 Baseline Characteristics of the Study Population[a]

	Female Players[b]	Male Players[c]
Age, y	16.5 ± 0.9	16.6 ± 0.8
Height, cm	169.6 ± 9.3	183.9 ± 6.8
Weight, kg	69.3 ± 8.9	80.1 ± 10.6
Time playing handball, y	9.4 ± 2.1	9.3 ± 2.3
Playing position, n (%)[d]		
Goalkeeper	37 (16)	41 (18)
Wing player	41 (18)	51 (23)
Line player	41 (18)	29 (13)
Back player	107 (47)	105 (46)
School grade, n (%)[d]		
First	115 (51)	100 (44)
Second	74 (33)	83 (37)
Third	37 (16)	43 (19)
History of shoulder pain, n (%)	77 (34)	66 (29)
Playing level, n (%)[d]		
Regional	169 (75)	175 (77)
National	57 (25)	51 (23)

[a]*Values are mean ± SD unless otherwise indicated.*
[b]*n = 180 (226 player-seasons).*
[c]*n = 164 (226 player-seasons).*
[d]*Number of player-seasons.*

supports previous research in adolescent handball[23] and other overhead sports.[21,22,26,27] Our results do not support the most recently published study of youth handball players, which reported an association between increased external rotation ROM and shoulder injury in female players but not in male players.[1] In professional male and female handball players, the literature is inconsistent—reduced total rotation[7] or increased internal rotation[2] may increase injury risk.

There could be several explanations for the diverse findings of these studies. Range of motion may be an injury risk factor for different age groups in handball. Range of motion measured on the bench may not correlate with the player's ROM during a handball throw.[30] If ROM measured outside the throwing environment is prone to substantial misclassification, this will most likely dilute true associations. Finally, there are several factors that may limit the ROM, such as the joint capsule, soft tissue tension, and the humeral retroversion seen in throwers.[33] Without considering all of these factors, it is difficult to draw strong conclusions regarding ROM measured on the bench.

Relationship Between Scapular Dyskinesis and Shoulder Injuries

We found a clear association between scapular dyskinesis during glenohumeral abduction and risk of shoulder injuries in male handball players, which supports the conclusions in previous research.[7,23] The association between shoulder injury and scapular dyskinesis during abduction makes clinical sense, because abduction (as opposed to flexion) is closer to the throwing position in handball. We did not find an association between scapular dyskinesis and shoulder injury in female players. Potential differences in throwing biomechanics between adolescent female and male players may explain these findings; however, we cannot rule out exposure misclassification or too few exposed cases, thus low statistical power.

Relationship Between Joint Position Sense and Shoulder Injuries

We did not find an association between joint position sense and shoulder injury in male and female players. To our knowledge, this is the first study to prospectively investigate joint position sense in relation to shoulder injuries in throwers. Joint position sense and performance have been investigated and compared between throwers and nonthrowers in several studies, with inconsistent results.[6,13,25]

TABLE 3 Hazard Rate Ratios of Shoulder Injury in the Dominant Arm in Adolescent Female and Male Handball Players

	Female Players (n = 180, 226 player-seasons)			Male Players (n = 164, 226 player-seasons)		
	Exposure, n[a]	Crude HRR[b]	Adjusted HRR[bc]	Exposure, n[a]	Crude HRR[b]	Adjusted HRR[bc]
Strength, N/kg						
Isometric external rotation	18/95	2.37 (1.03, 5.45)	2.37 (1.03, 5.44)	11/102	0.99 (0.43, 2.28)	1.02 (0.44, 2.36)
Isometric internal rotation	18/95	2.43 (1.06, 5.58)	2.44 (1.06, 5.61)	9/104	0.66 (0.28, 1.55)	0.74 (0.31, 1.75)
Eccentric external rotation	14/99	1.25 (0.58, 2.71)	1.21 (0.57, 2.62)	9/104	0.64 (0.27, 1.50)	0.70 (0.29, 1.64)
Isometric abduction	14/99	1.14 (0.53, 2.47)	1.10 (0.50, 2.38)	12/101	1.13 (0.49, 2.62)	1.19 (0.51, 2.77)
Isometric external rotation/isometric internal rotation <0.75	13/103	0.87 (0.40, 1.87)	0.85 (0.39, 1.83)	18/140	2.04 (0.69, 6.04)	2.00 (0.68, 5.92)
Eccentric external rotation/isometric internal rotation <0.75	2/31	0.45 (0.11, 1.88)	0.41 (0.10, 1.73)	7/63	1.08 (0.44, 2.66)	1.10 (0.45, 2.69)
Range of motion, deg						
External rotation	11/104	0.71 (0.33, 1.55)	0.74 (0.34, 1.62)	10/107	0.84 (0.36, 1.95)	0.74 (0.31, 1.73)
Internal rotation	17/105	1.56 (0.70, 3.51)	1.59 (0.70, 3.54)	11/102	1.06 (0.46, 2.44)	1.03 (0.45, 2.37)
Total ROM[d]	11/103	0.70 (0.32, 1.53)	0.70 (0.32, 1.53)	10/103	0.87 (0.37, 2.00)	0.77 (0.33, 1.81)
Total ROM[d] (dominant/nondominant)	14/100	1.21 (0.56, 2.62)	1.30 (0.59, 2.83)	8/108	0.56 (0.24, 1.35)	0.53 (0.22, 1.25)
Scapular dyskinesis[e]						
During flexion	4/53	0.50 (0.17, 1.45)	0.49 (0.17, 1.44)	16/129	1.44 (0.56, 3.67)	1.53 (0.60, 3.94)
During abduction	2/8	1.65 (0.39, 6.98)	1.53 (0.36, 6.52)	11/40	3.45 (1.49, 7.95)	3.43 (1.49, 7.92)
Joint position sense						
Mean error from target angle	14/101	1.06 (0.49, 2.29)	1.06 (0.49, 2.29)	12/104	1.14 (0.49, 2.63)	1.12 (0.48, 2.59)

Abbreviations: HRR, hazard rate ratio; ROM, range of motion.
[a]*Values are number of exposed cases/nonaccess.*
[b]*Values in parentheses are 95% confidence interval.*
[c]*Adjusted for playing position.*
[d]*Sum of IR and ER.*
[e]*The analyses in female players are based on 225 player-seasons due to 1 player who declined to perform this test.*

No correlation has been found between joint position sense and throwing speed or accuracy.[19]

Methodological Considerations

Our study had several strengths. The first was a low risk of misclassification of the outcome, owing to a widely used and valid questionnaire.[9,15] The second was a very high response rate (overall weekly average of 92%), making the risk of selection bias negligible. The fact that there were no differences in the exposure values at baseline between players who dropped out, players with a low response rate (less than 25%), and players with a higher response rate (25% or greater) minimized the risk of selection bias. Finally, the reliability of the clinical measures was good to excellent, which reduced the risk of misclassification.

The study also had limitations. This was one of the largest prospective cohort studies to be conducted in adolescent overhead athletes. However, some of the results (eg, scapular dyskinesis in female players) should be interpreted with caution, due to few exposed cases and low statistical power. Because competitive-season data were reported once a week, players might have had trouble recalling the exact time at risk during the past week. However, these potential misclassifications were nondifferential, given that they were most likely not associated with the exposures measured at baseline. Reliability of judging scapular dyskinesis was good. However, there could have been a risk of misclassification of scapular dyskinesis in the female players, as the sports bra made it more difficult to visually identify scapular dyskinesis.

There could have been a risk of nondifferential misclassification of strength in the male players. Because we measured rotational strength in the seated 90°-90° position, the players were close to their maximum external rotation ROM, which might have affected isometric external rotation strength. Male players might have been particularly affected, because they often have less external rotation ROM than female players. These potential misclassifications of exposure may explain some of the sex differences.

Although we had data to control for a large number of potential confounders, the number of events limited the possibility to include several confounders in the same model. Hence, only 1 factor (playing position) was included in the adjusted model. However, we conducted 3 sensitivity tests that each included one of the other potential confounders (school grade, school, and playing level) in the model, and the main results did not change.

We did not collect information about sleep pattern or nutritional intake, which may be associated with higher risk of sports injuries.[32] Thus, our results may be prone to residual confounding. Importantly, residual confounding is unlikely to influence the strong risk estimates found for isometric external rotation and isometric internal rotation strength in female players and for scapular dyskinesis in male players.

CONCLUSION

In adolescent elite handball, male players with preseason scapular dyskinesis and female players with preseason internal or external rotational shoulder weakness had an increased rate of shoulder injury. ◉

KEY POINTS

FINDINGS: The shoulder injury rate among adolescent elite handball players was higher among male players entering the competitive season with scapular dyskinesis and among female players entering the competitive season with internal or external rotational weakness.

IMPLICATIONS: Adolescent female players entering the season with shoulder internal or external rotation weakness and adolescent male players entering the season with scapular dyskinesis during abduction are more likely to report shoulder injuries during the playing season. Whether shoulder control and strength training would reduce the incidence of shoulder injury in this population should be studied in randomized controlled trials.

CAUTION: Due to low statistical power, some of the findings, such as scapular dyskinesis in female players, should be interpreted cautiously.

ACKNOWLEDGMENT: *We acknowledge all the schools and players participating in this study, and also the test team who collected all the data.*

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors were involved in the conception and design of the study. Drs Asker and Skillgate were responsible for recruitment and data collection. All authors contributed to the writing and revision of the manuscript and approved the final version of the manuscript. Dr Skillgate is the study guarantor.

PATIENT AND PUBLIC INVOLVEMENT: To facilitate the feasibility of the study, during the planning stage, several meetings and discussions with a focus group of handball coaches and the educational committee of the Swedish Handball Federation were held.

DATA SHARING: There are no data available.

REFERENCES

1. Achenbach L, Laver L, Walter SS, Zeman F, Kuhr M, Krutsch W. Decreased external rotation strength is a risk factor for overuse shoulder injury in youth elite handball athletes. *Knee Surg Sports Traumatol Arthrosc*. In press. https://doi.org/10.1007/s00167-019-05493-4
2. Andersson SH, Bahr R, Clarsen B, Myklebust G. Risk factors for overuse shoulder injuries in a mixed-sex cohort of 329 elite handball players: previous findings could not be confirmed. *Br J Sports Med*. 2018;52:1191-1198. https://doi.org/10.1136/bjsports-2017-097648
3. Asker M, Brooke HL, Waldén M, et al. Risk factors for, and prevention of, shoulder injuries in overhead sports: a systematic review with best-evidence synthesis. *Br J Sports Med*. 2018;52:1312-1319. https://doi.org/10.1136/bjsports-2017-098254
4. Asker M, Holm LW, Källberg H, Waldén M, Skillgate E. Female adolescent elite handball players are more susceptible to shoulder

problems than their male counterparts. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:1892-1900. https://doi.org/10.1007/s00167-018-4857-y
5. Asker M, Waldén M, Källberg H, Holm LW, Skillgate E. A prospective cohort study identifying risk factors for shoulder injuries in adolescent elite handball players: the Karolinska Handball Study (KHAST) study protocol. *BMC Musculoskelet Disord*. 2017;18:485. https://doi.org/10.1186/s12891-017-1852-2
6. Badagliacco JA, Karduna A. College pitchers demonstrate directional differences in shoulder joint position sense compared with controls. *J Sport Rehabil*. 2018;27:301-305. https://doi.org/10.1123/jsr.2017-0007
7. Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med*. 2014;48:1327-1333. https://doi.org/10.1136/bjsports-2014-093702
8. Clarsen B, Bahr R, Heymans MW, et al. The prevalence and impact of overuse injuries in five Norwegian sports: application of a new surveillance method. *Scand J Med Sci Sports*. 2015;25:323-330. https://doi.org/10.1111/sms.12223
9. Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire. *Br J Sports Med*. 2013;47:495-502. https://doi.org/10.1136/bjsports-2012-091524
10. Cools AM, De Wilde L, Van Tongel A, Ceyssens C, Ryckewaert R, Cambier DC. Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. *J Shoulder Elbow Surg*. 2014;23:1454-1461. https://doi.org/10.1016/j.jse.2014.01.006
11. Cools AM, Vanderstukken F, Vereecken F, et al. Eccentric and isometric shoulder rotator cuff strength testing using a hand-held dynamometer: reference values for overhead athletes. *Knee Surg Sports Traumatol Arthrosc*. 2016;24:3838-3847. https://doi.org/10.1007/s00167-015-3755-9
12. Dover G, Powers ME. Reliability of joint position sense and force-reproduction measures during internal and external rotation of the shoulder. *J Athl Train*. 2003;38:304-310.
13. Dover GC, Kaminski TW, Meister K, Powers ME, Horodyski M. Assessment of shoulder proprioception in the female softball athlete. *Am J Sports Med*. 2003;31:431-437. https://doi.org/10.1177/03635465030310031801
14. Edouard P, Degache F, Oullion R, Plessis JY, Gleizes-Cervera S, Calmels P. Shoulder strength imbalances as injury risk in handball. *Int J Sports Med*. 2013;34:654-660. https://doi.org/10.1055/s-0032-1312587
15. Ekman E, Frohm A, Ek P, Hagberg J, Wirén C, Heijne A. Swedish translation and validation of a web-based questionnaire for registration of overuse problems. *Scand J Med Sci Sports*. 2015;25:104-109. https://doi.org/10.1111/sms.12157
16. Fahlström M, Söderman K. Decreased shoulder function and pain common in recreational badminton players. *Scand J Med Sci Sports*. 2007;17:246-251. https://doi.org/10.1111/j.1600-0838.2006.00562.x
17. Fahlström M, Yeap JS, Alfredson H, Söderman K. Shoulder pain – a common problem in world-class badminton players. *Scand J Med Sci Sports*. 2006;16:168-173. https://doi.org/10.1111/j.1600-0838.2004.00427.x
18. Forthomme B, Croisier JL, Delvaux F, Kaux JF, Crielaard JM, Gleizes-Cervera S. Preseason strength assessment of the rotator muscles and shoulder injury in handball players. *J Athl Train*. 2018;53:174-180. https://doi.org/10.4085/1062-6050-216-16
19. Freeston J, Adams RD, Rooney K. Shoulder proprioception is not related to throwing speed or accuracy in elite adolescent male baseball players. *J Strength Cond Res*. 2015;29:181-187. https://doi.org/10.1519/JSC.0000000000000507
20. Giroto N, Hespanhol Junior LC, Gomes MR, Lopes AD. Incidence and risk factors of injuries in Brazilian elite handball players: a prospective cohort study. *Scand J Med Sci Sports*. 2017;27:195-202. https://doi.org/10.1111/sms.12636
21. Keller RA, De Giacomo AF, Neumann JA, Limpisvasti O, Tibone JE. Glenohumeral internal rotation deficit and risk of upper extremity injury in overhead athletes: a meta-analysis and systematic review. *Sports Health*. 2018;10:125-132. https://doi.org/10.1177/1941738118756577
22. Miller AH, Evans K, Adams R, Waddington G, Witchalls J. Shoulder injury in water polo: a systematic review of incidence and intrinsic risk factors. *J Sci Med Sport*. 2018;21:368-377. https://doi.org/10.1016/j.jsams.2017.08.015
23. Møller M, Nielsen RO, Attermann J, et al. Handball load and shoulder injury rate: a 31-week cohort study of 679 elite youth handball players. *Br J Sports Med*. 2017;51:231-237. https://doi.org/10.1136/bjsports-2016-096927
24. Myklebust G, Hasslan L, Bahr R, Steffen K. High prevalence of shoulder pain among elite Norwegian female handball players. *Scand J Med Sci Sports*. 2013;23:288-294. https://doi.org/10.1111/j.1600-0838.2011.01398.x
25. Nodehi-Moghadam A, Nasrin N, Kharazmi A, Eskandari Z. A comparative study on shoulder rotational strength, range of motion and proprioception between the throwing athletes and non-athletic persons. *Asian J Sports Med*. 2013;4:34-40. https://doi.org/10.5812/asjsm.34528
26. Norton R, Honstad C, Joshi R, Silvis M, Chinchilli V, Dhawan A. Risk factors for elbow and shoulder injuries in adolescent baseball players: a systematic review. *Am J Sports Med*. 2019;47:982-990. https://doi.org/10.1177/0363546518760573
27. Oyama S, Hibberd EE, Myers JB. Preseason screening of shoulder range of motion and humeral retrotorsion does not predict injury in high school baseball players. *J Shoulder Elbow Surg*. 2017;26:1182-1189. https://doi.org/10.1016/j.jse.2017.03.038
28. Serrien B, Clijsen R, Blondeel J, Goossens M, Baeyens JP. Differences in ball speed and three-dimensional kinematics between male and female handball players during a standing throw with run-up. *BMC Sports Sci Med Rehabil*. 2015;7:27. https://doi.org/10.1186/s13102-015-0021-x
29. Uhl TL, Kibler WB, Gecewich B, Tripp BL. Evaluation of clinical assessment methods for scapular dyskinesis. *Arthroscopy*. 2009;25:1240-1248. https://doi.org/10.1016/j.arthro.2009.06.007
30. van den Tillaar R. Comparison of range of motion tests with throwing kinematics in elite team handball players. *J Sports Sci*. 2016;34:1976-1982. https://doi.org/10.1080/02640414.2016.1149601
31. Van Den Tillaar R, Cabri JM. Gender differences in the kinematics and ball velocity of overarm throwing in elite team handball players. *J Sports Sci*. 2012;30:807-813. https://doi.org/10.1080/02640414.2012.671529
32. von Rosen P, Frohm A, Kottorp A, Fridén C, Heijne A. Too little sleep and an unhealthy diet could increase the risk of sustaining a new injury in adolescent elite athletes. *Scand J Med Sci Sports*. 2017;27:1364-1371. https://doi.org/10.1111/sms.12735
33. Whiteley R, Oceguera M. GIRD, TRROM, and humeral torsion-based classification of shoulder risk in throwing athletes are not in agreement and should not be used interchangeably. *J Sci Med Sport*. 2016;19:816-819. https://doi.org/10.1016/j.jsams.2015.12.519

APPENDIX A

WEEKLY QUESTIONNAIRE USED IN THE KAROLINSKA HANDBALL STUDY (TRANSLATED FROM SWEDISH)

Please answer all questions, regardless of whether you have problems in your shoulders. Select the alternative that is most appropriate for you, and if you are unsure, try to give an answer as best you can anyway.

1. How many **minutes** of handball matches have you played during the past week? ________
2. How many **hours** of handball training on the handball court have you done during the past week? ________
3. How many **hours** of handball training off court have you done during the past week (eg, running, strength and conditioning)? ________

Acute Injury

4. Have you had any traumatic injury during the past week (regardless of area and type of injury, eg, sprains, strains, or falls)
   ☐ No
   ☐ Yes
   If yes, which body part? ________________________________

Shoulder Problems, Acute or Nonacute Onset

The term "shoulder problems" refers to pain, aching, stiffness, looseness, or other complaints related to the shoulder.

5. Have you had any difficulties participating in normal training and competition due to shoulder problems during the past week?
   ☐ Full participation without shoulder problems
   ☐ Full participation, but with shoulder problems
   ☐ Reduced participation due to shoulder problems
   ☐ Cannot participate due to shoulder problems
   ☐ Reduced participation/cannot participate due to other reasons than shoulder problems
   What reason? ____
6. To what extent have you reduced your training volume due to shoulder problems during the past week?
   ☐ No reduction
   ☐ To a minor extent
   ☐ To a moderate extent
   ☐ To a major extent
   ☐ Cannot participate at all due to shoulder problems
7. To what extent have shoulder problems affected your performance during the past week?
   ☐ No effect
   ☐ To a minor extent
   ☐ To a moderate extent
   ☐ To a major extent
   ☐ Cannot participate at all due to shoulder problems
8. To what extent have you experienced shoulder pain related to your sport during the past week?
   ☐ No pain
   ☐ Mild pain
   ☐ Moderate pain
   ☐ Severe pain
9. If you experienced any shoulder problems, please mark which shoulder you have/had most problems with.
   ☐ Left
   ☐ Right

APPENDIX B

INTRAEXAMINER RELIABILITY FOR THE ASSESSMENT OF STRENGTH, RANGE OF MOTION, JOINT POSITION SENSE, AND SCAPULAR DYSKINESIS

	Test Leaders During Season 1		Test Leaders During Season 2	
Test	**$ICC_{3,1}$[a]**	**SEM**	**$ICC_{3,1}$[a]**	**SEM**
Isometric external rotation	0.91 (0.89, 0.93)	6.96	NA[b]	NA[b]
Isometric internal rotation	0.96 (0.95, 0.97)	8.47	NA[b]	NA[b]
Eccentric external rotation	0.92 (0.91, 0.93)	8.24	NA[b]	NA[b]
Isometric abduction	0.92 (0.90, 0.94)	7.18	NA[b]	NA[b]
External rotation	0.97 (0.95, 0.98)	2.03	0.83 (0.78, 0.89)	4.25
Internal rotation	0.96 (0.94, 0.96)	1.60	0.88 (0.85, 0.90)	3.43
Joint position sense	0.68 (0.60, 0.75)	6.90	0.95 (0.93, 0.96)	2.64
Test	**Cohen κ[a]**	**Agreement, %**	**Cohen κ[a]**	**Agreement, %**
Scapular dyskinesis: abduction	0.92 (0.86, 0.96)	97	NA[b]	NA[b]
Scapular dyskinesis: flexion	0.85 (0.74, 0.91)	93	NA[b]	NA[b]

Abbreviations: ICC, intraclass correlation coefficient; NA, not applicable; SEM, standard error of measurement.
[a]*Values in parentheses are 95% confidence interval.*
[b]*The same test leader was used for both season 1 and season 2.*

SUSANNE BEISCHER, PT, PhD[1,2] • **LINNÉA GUSTAVSSON**, PT[2] • **ERIC HAMRIN SENORSKI**, PT, PhD[1,2]
JÓN KARLSSON, MD, PhD[3] • **CHRISTOFFER THOMEÉ**, BS[2] • **KRISTIAN SAMUELSSON**, MD, PhD[3] • **ROLAND THOMEÉ**, PT, PhD[1,2]

Young Athletes Who Return to Sport Before 9 Months After Anterior Cruciate Ligament Reconstruction Have a Rate of New Injury 7 Times That of Those Who Delay Return

OBJECTIVE: To investigate the association between sustaining a second anterior cruciate ligament (ACL) injury and (1) time to return to sport, (2) symmetrical muscle function, and (3) symmetrical quadriceps strength at the time of return to sport in young athletes after primary ACL reconstruction.

DESIGN: Prospective cohort study.

METHODS: Patient demographics and results from 5 tests of muscle function (2 strength tests and 3 hop tests) were extracted from a rehabilitation registry. A questionnaire was sent to athletes (15-30 years old) who were involved in knee-strenuous sport before the injury and had undergone primary ACL reconstruction to determine time of return to knee-strenuous sport (preinjury Tegner Activity Scale score of 6 or greater). We used the Cox proportional hazard regression model to analyze time to event.

RESULTS: One hundred fifty-nine (32% of the initial sample) athletes (mean ± SD age, 21.5 ± 4.4 years; 50% female) were included. Athletes with a higher preinjury Tegner Activity Scale score had a higher rate of second ACL injury (hazard ratio = 2.1; 95% confidence interval: 1.2, 3.6; $P<.01$). Athletes who returned to knee-strenuous sport before 9 months after reconstruction had a higher rate of second ACL injury (hazard ratio = 6.7; 95% confidence interval: 2.6, 16.7; $P<.001$). There was no association between symmetrical muscle function or quadriceps strength and second ACL injury.

CONCLUSION: Returning to knee-strenuous sport before 9 months after ACL reconstruction was associated with an approximately 7-fold increased rate of sustaining a second ACL injury. Achieving symmetrical muscle function or quadriceps strength was not associated with new ACL injury in young athletes. *J Orthop Sports Phys Ther 2020;50(2):83-90. doi:10.2519/jospt.2020.9071*

KEY WORDS: *adolescent, rehabilitation, subsequent ACL injury*

Approximately 1 in 4 patients who are 25 years of age or younger and return to high-risk sport (eg, soccer and team handball) after primary anterior cruciate ligament (ACL) reconstruction sustain a second ACL injury.[28] Given that younger patients return to sport after ACL reconstruction in greater numbers than older patients, their greater exposure may explain the elevated reinjury risk.[3,4,17,27]

There are conflicting findings regarding the relationship between passing specific return-to-sport tests and the risk of second ACL injury.[10,15,19] Among youth athletes with a mean age of 17 years, there were no differences in strength and hop performance at the time of return-to-sport clearance between those who successfully resumed their preinjury sports participation and those who sustained a second ACL injury.[15] Professional athletes who did not meet 6 discharge criteria before returning to sport had 4 times the risk of graft rupture compared to their peers who met the discharge criteria.[19] In addition, patients with more symmetrical quadriceps strength and who returned to sport at least 9 months after surgery had an 84% reduction in the rate of knee injuries.[10]

Key considerations when interpreting previous research on the relationship between passing return-to-sport discharge criteria and second ACL injury include the heterogeneous populations (eg, profession-

[1]Unit of Physiotherapy, Department of Health and Rehabilitation, Institute of Neuroscience and Physiology, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden. [2]Sportrehab Sports Medicine Clinic, Gothenburg, Sweden. [3]Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska University Hospital, University of Gothenburg, Mölndal, Sweden. Ethical approval was obtained from the Regional Ethical Review Board in Gothenburg, Sweden (registration numbers 265-13, T023-17). This study was funded by grants from the Swedish Research Council for Sport Science, by the Local Research and Development Board for Gothenburg and Södra Bohuslän, and by the Unit of Physiotherapy, Institute of Neuroscience and Physiology, Sahlgrenska Academy, University of Gothenburg. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Susanne Beischer, Unit of Physiotherapy, Department of Health and Rehabilitation, Institute of Neuroscience and Physiology, Sahlgrenska Academy, University of Gothenburg, Box 455, SE-405 30 Gothenburg, Sweden. E-mail: susanne.beischer@gu.se

al athletes,[19] youth athletes,[15] recreational athletes[10]) and heterogeneous outcomes (eg, graft ruptures[19] or all knee-related reinjuries[10]) evaluated in previous studies. There remain unanswered questions about the protective effects of delaying return to sport and achieving symmetrical muscle function for young athletes involved in knee-strenuous sport, especially because of the low proportion of young athletes who achieve symmetrical muscle function prior to returning to sport.[4,25]

The aim of this study was to investigate the association between sustaining a second ACL injury and (1) time to return to sport, (2) symmetrical muscle function, and (3) symmetrical quadriceps strength at the time of return to sport in young athletes after primary ACL reconstruction. In addition, the association between demographics and sustaining a second ACL injury was assessed.

METHODS

This prospective observational study was based on data from an ACL rehabilitation outcome registry, "Project ACL."[4,12] All patients received written information about the study, and informed consent was obtained. The data were coded, and none of the included athletes could be identified during analyses. Ethical approval was obtained from the Regional Ethical Review Board in Gothenburg (registration numbers 265-13, T023-17). All data were extracted from the Project ACL database on November 8, 2018.

Patients

We included patients with primary ACL reconstruction (surgery between March 2013 and December 2017) who were aged between 15 and 30 years at time of surgery and active in knee-strenuous sport before ACL injury (preinjury Tegner Activity Scale[24] score of 6 or greater). We excluded patients who had more than 1 subsequent ACL injury registered in the Project ACL database, who had any complication during the muscle function tests that was considered to have influenced the results (eg, muscle strain or knee pain), or who did not respond to the study-specific questionnaire (**TABLE 1**).

Independent Variables

Time to Return to Sport We sent an online questionnaire (**TABLE 1**) to athletes in the Project ACL database who had performed muscle function tests at the 8-, 12-, and 18-month follow-ups. Our questionnaire included the question, "Have you, since your primary ACL reconstruction, reached any of these levels of physical activity?" (yes/no) (**TABLE 1**). If the athlete answered "yes," then he or she was asked, "Please specify when [month/year] you returned to at least level 6" (on the Tegner Activity Scale). We calculated the variable "time (months) of return to knee-strenuous sport" based on the questionnaire responses. We pilot tested the questionnaire with 10 patients with ACL injury (not included in the study) to improve face validity, and made no changes to the questionnaire.

The online questionnaire was sent to 494 athletes who had fulfilled the inclusion criteria. The athletes who did not respond to the questionnaire received up to 2 reminders by text message within a week of first contact, followed by up to 2 reminders by e-mail. Finally, nonresponders were contacted by telephone. A total of 344 athletes responded.

Achieving Symmetrical Muscle Function Data from strength and hop tests from the follow-up closest to return to sport were extracted from the Project ACL database (**TABLE 2**).

All athletes completed a test battery of 2 strength tests (either isokinetic or isometric knee extension and knee flexion, reflecting quadriceps and hamstring strength) and 3 single-leg hop tests. Before completing the test battery, athletes had to fulfill the following criteria: minimal knee pain, minimal knee effusion, performed single-leg exercise without

TABLE 1 Project-Specific Questionnaire Regarding Return to Sport

1. Have you, since your primary anterior cruciate ligament reconstruction, reached any of these levels of physical activity? (yes/no)
   If yes:
   1a. Please specify when you returned to at least level 6 (month/year)

Tegner Activity Scale Levels 6 to 10 and Corresponding Sports
Level 6: baseball, hurdling, orienteering, snowboarding
Level 7: badminton, high jump, tennis, downhill skiing, volleyball
Level 8: basketball, handball, floorball, long jump
Level 9: football, ice hockey, mogul skiing
Level 10: football: national or international level, American football, wrestling, figure skating

TABLE 2 Follow-ups and Number of Athletes Included in the Analysis, With Respect to Time to RTS

Time to RTS, mo	Month Data Were Extracted	Included Athletes (n = 159), n (%)
7-11	8	101 (63.5)
12-17	12	40 (25.2)
18-23	18	13 (8.2)
24-35	24	4 (2.5)
≥36	36	1 (0.6)

Abbreviation: RTS, return to sport.

perceiving new or increased symptoms, and trained single-leg maximal hop tests with their responsible physical therapist outside the testing environment for Project ACL data collection. At the time of follow-up, the test leader assessed the patient's health status to ensure that he or she was well prepared to perform the tests.

The test procedure, including a warm-up procedure, familiarization, and maximum repetitions in both strength and hop tests, has been described in detail in previous studies (**TABLE 3**).[4,13] The results from the strength and hop tests were expressed as the limb symmetry index (LSI), defined as the ratio between the injured side and the uninjured side and expressed as a percentage. Symmetrical muscle function was defined as achieving an LSI of 90% or greater in all 5 tests of muscle function.

The LSI for the strength tests was calculated from isometric tests of quadriceps strength and hamstring strength using the F200 DMS-EVE (David Health Solutions Ltd, Helsinki, Finland) and from isokinetic concentric strength tests of the quadriceps and hamstrings using the Biodex System 4 (Biodex Medical Systems, Shirley, NY). In our study, the isometric tests contributed to 9% of the total muscle strength LSI data. Isometric and isokinetic strength tests are highly reliable (intraclass correlation coefficient = 0.91-0.99).[1,7,21,23]

After the strength testing, the participants performed 3 single-leg hop tests in the following order: vertical hop, hop for distance, and side hop.[4,13] High test-retest reliability for the 3 different tests in the battery of hop tests has been reported (intraclass correlation coefficient = 0.93-0.97).[11]

Patient Characteristics

We extracted age at primary ACL reconstruction, sex, anthropometric data, and preinjury Tegner Activity Scale score from the Project ACL database.

Outcome

The primary outcome was sustaining a subsequent ACL injury (yes/no). The injuries were confirmed by the treating physical therapist or orthopaedic surgeon. There were no specific criteria to verify the ACL injury. No maximum time of follow-up was determined. Data regarding subsequent ACL injury were extracted from the Project ACL database, comprising the number of ACL injuries, date of the subsequent ACL injury, and side of injury.

Statistical Analysis

Statistical analysis was performed using the SAS statistical analysis system (SAS/STAT Version 14.2; SAS Institute Inc, Cary, NC). Descriptive statistics for patient demographics and outcomes were reported with count and proportion for categorical variables. Continuous variables were reported with mean, SD, median, and range.

For comparisons between athletes with complete data and those lost to follow-up, we used the Fisher exact test (lowest 1-sided *P* value multiplied by 2) for dichotomous variables, the Mantel-Haenszel chi-square exact test for ordered categorical variables, and the Mann-Whitney *U* test for continuous variables.

We used a Cox proportional hazard regression model for the analyses of time to second ACL injury, with time to return to sport, symmetrical muscle function, symmetrical quadriceps strength, and demographics as independent variables. Time to return to sport was dichotomized into less than 9 months and 9 months or greater.[10] Time 0 was defined as the first month of participation in sports equal to knee-strenuous sport (ie, a Tegner Activity Scale score of 6 or greater). Symmetrical muscle function was defined as achieving an LSI of 90% or greater in all 5 tests of muscle function. Symmetrical quadriceps strength was defined as achieving an LSI of 90% or greater in quadriceps strength. Hazard ratios (HRs) were calculated for descriptive purposes.

Data were checked for nonproportionality using the supremum test for proportional hazards assumption, and by introducing a time-dependent covariate (the interaction between the

TABLE 3 Tests of Muscle Function[a]

	Knee Angle, deg	Practice Trials, n (% 1-RM)	Maximum Repetitions, n	Rest Between Repetitions, s
Knee extension			3-5	40
Isometric[b]	60	3 (70, 80, 90)		
Isokinetic[c]	0-90	1-2 (90)		
Knee flexion			3-5	40
Isometric[d]	30	3 (70, 80, 90)		
Isokinetic[c]	0-90	1-2 (90)		
Single-leg vertical hop[e]	...	2	3	20-30
Single-leg hop for distance	...	2	3	20-30
Single-leg side hop[f]	...	10	1	180

Abbreviation: RM, repetition maximum.
[a]*Modified under a Creative Commons CC-BY-NC license (https://creativecommons.org/licenses/by-nc/4.0/) with permission from Beischer S, Hamrin Senorski E, Thomeé C, Samuelsson K, Thomeé R. Knee strength, hop performance and self-efficacy at 4 months are associated with symmetrical knee muscle function in young athletes 1 year after an anterior cruciate ligament reconstruction. BMJ Open Sport Exerc Med. 2019;5:e000504. https://doi.org/10.1136/bmjsem-2018-000504*
[b]*Measured with the F200 DMS-EVE (David Health Solutions Ltd, Helsinki, Finland).*
[c]*Measured with the Biodex System 4 (Biodex Medical Systems, Shirley, NY) at 90°/s.*
[d]*Measured with the F300 DMS-EVE (David Health Solutions Ltd).*
[e]*Measured with MUSCLELAB (Ergotest Innovation AS, Porsgrunn, Norway).*
[f]*As many hops as possible in 30 seconds over 2 lines 40 cm apart.*

independent variable of time to return to sport and the time variable of time from return to sport). To compare models, generalized R^2 was calculated for the univariable analysis. We planned a multiple survival analysis with stepwise Cox proportional hazard regression. However, a model based on fewer than 20 events would have been overfitted with unreliable results[5] and was not performed.

Sensitivity analyses were performed to check for influential outliers by excluding 10% of the variables with the most influence on significant factors. In addition, we analyzed the association between time to return to sport and subsequent ACL injury for all eligible athletes, regardless of whether they had performed the muscle function tests. Significance tests were conducted at the 5% level.

RESULTS

One hundred fifty-nine (32%) athletes completed the muscle function tests. The main reason for exclusion from further analyses was that the athlete had not performed tests of muscle function close to the time of return to sport (n = 105) (**FIGURE 1**).

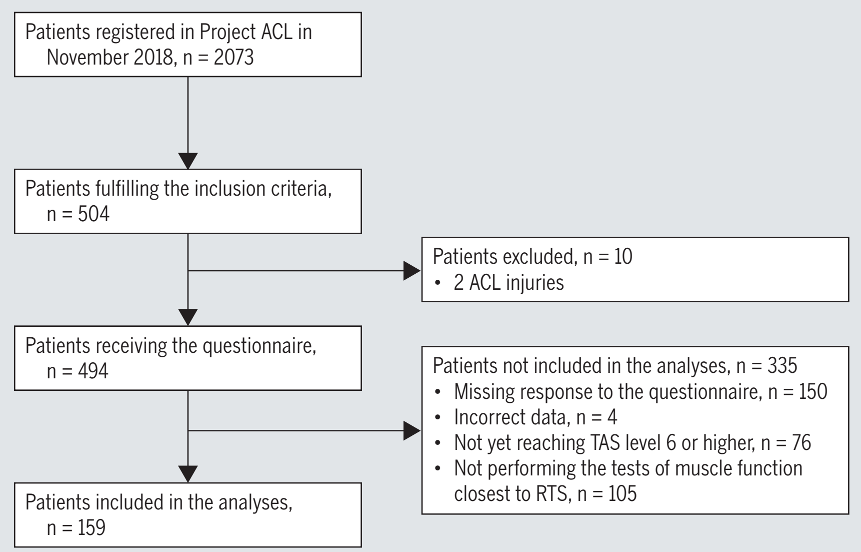

FIGURE 1. Flow chart of inclusion and exclusion. Abbreviations: ACL, anterior cruciate ligament; RTS, return to sport; TAS, Tegner Activity Scale.

There were no differences in sex, age, preinjury level of physical activity, and anthropometrics between athletes with complete data (n = 159) and athletes with missing data from the muscle function tests or the study-specific questionnaire (n = 335). The athletes with complete data had a shorter time from injury to ACL reconstruction compared with the excluded individuals, by an average of 2 months (P = .007).

The athletes (n = 159) had an average age of 21.5 ± 4.4 years at their primary ACL reconstruction, and 50% were female. The median time to return to sport for all included athletes was 11.0 months (range, 7.5-37.9 months). One hundred one athletes (64%) returned to knee-strenuous sport between 7 and 11 months after ACL reconstruction (**TABLE 2**). The median follow-up time was 15.5 months (range, 0.4-46.5 months) after return to sport, and the time between return to sport and athletes answering the study-specific questionnaire ranged from 2 days to 5 years, with an average of 1.3 years. Athletes performed the tests of muscle function 65 ± 47 days before return to sport. The average LSI for each of the 5 muscle function tests varied between 89% and 99%. Twenty-four percent (n = 39) of the athletes achieved symmetrical muscle function across the battery of tests before returning to knee-strenuous sport.

Eighteen (11%) athletes sustained a new ACL injury that was registered in Project ACL: 10 graft ruptures and 8 contralateral ACL ruptures (**TABLE 4**) occurred between 9 and 36 months after ACL reconstruction (median, 19 months). Athletes who sustained a new ACL injury returned to knee-strenuous sport, on average, 10.1 ± 3.3 months (range, 7.6-19.4 months) after ACL reconstruction, compared with 12.7 ± 4.8 months (range, 7.5-37.9 months) for athletes with no new ACL injury (**TABLE 5**). Ten of the 33 athletes who returned to knee-strenuous sport earlier than 9 months after reconstruction sustained a new ACL injury. Twelve (67%) of the second ACL injuries occurred in athletes who returned to knee-strenuous sport between 8 and 9 months after ACL reconstruction.

Athletes who returned to knee-strenuous sport at 9 months or later after surgery had a lower rate of new ACL injury compared with those who returned earlier than 9 months after ACL reconstruction (HR = 0.15; 95% confidence interval [CI]: 0.06, 0.39; P<.001) (**TABLE 6, FIGURE 2**). Alternatively expressed, athletes who returned to knee-strenuous sport earlier than 9 months had an approximately 7-fold higher rate of new ACL injury compared with those who returned at 9 months or later after surgery (HR = 6.7; 95% CI: 2.6, 16.7; P<.001).

Achieving symmetrical muscle function in 5 tests (P = .61) or symmetry in quadriceps strength (P = .15) was not associated with new ACL injury (**TABLE 6**).

Sensitivity Analyses

When we excluded 10% of the events with the strongest influence on the analysis of association between time to return to sport and new ACL injury (n = 159), the HR reduced from 6.7 to 5.6 (95% CI: 2.1, 16.7; P<.001).

When data from athletes, irrespective of whether they had performed the tests of muscle function, were analyzed (n =

264; 20 new ACL injuries), athletes who returned to knee-strenuous sport earlier than 9 months after ACL reconstruction had an approximately 3-fold higher rate of new ACL injury compared with those who returned at 9 months or later (HR = 2.7; 95% CI: 1.1, 6.7; P = .027). There was no relationship between time to return to sport and new ACL injury when we excluded the 10% of events with the strongest influence on the analysis. The results from these additional univariable analyses are presented in the **APPENDIX** (available at www.jospt.org).

DISCUSSION

Young athletes who returned to knee-strenuous sport earlier than 9 months after ACL reconstruction had approximately 3 to 7 times the rate of new ACL injury compared with those who delayed return to sport until at least 9 months after surgery. Eighteen (11%) athletes sustained a second ACL injury. Ten of the 33 athletes who returned to knee-strenuous sport earlier than 9 months after reconstruction sustained a new ACL injury. There were no associations between sustaining a subsequent ACL injury and achieving symmetrical muscle function or quadriceps strength.

Time to Return to Sport

Athletes who had returned to knee-strenuous sport before 9 months after reconstruction had an approximately 7-fold higher rate of second ACL injury compared with those who returned at 9 months or later. The analysis that included data from athletes irrespective of whether they had performed the tests of muscle function (n = 264) revealed a similar result, even though the HR was somewhat lower, showing a 3-fold higher rate of second ACL injury in athletes who had returned to knee-strenuous sport earlier than 9 months after surgery. Even though some of the included athletes returned to sports that were less demanding of knee function than in other studies,[6,10] our results mirror the findings of previous research.

Achieving Symmetrical Muscle Function

We did not find an association between achieving symmetrical muscle function and sustaining a second ACL injury. However, only 5 (28%) of the athletes who sustained a second ACL injury, and 33 (23%) of the athletes who did not, regained symmetrical muscle function close to return to sport. The fact that few athletes had symmetrical muscle function, in combination with a relatively limited population (n = 159), may explain

TABLE 4 Baseline Demographics, Stratified by Athletes With and Without Subsequent ACL Injury[a]

	Subsequent ACL Injury (n = 18)	No Subsequent ACL Injury (n = 141)	P Value
Patient sex, n (%)			.47
Female	11 (61)	59 (49)	
Height, cm	171.2 ± 8.3	174.7 ± 9.5	.13
Weight, kg	67.2 ± 8.5	71.2 ± 12.5	.21
Preinjury TAS score, n (%)			.029
6	0 (0.0)	6 (4.3)	
7	2 (11.1)	18 (12.8)	
8	3 (16.7)	43 (30.5)	
9	5 (27.8)	51 (36.2)	
10	8 (44.4)	23 (16.3)	
Graft choice, n (%)			.099
Hamstring	13 (72.2)	120 (87.0)	
Patella	4 (22.2)	17 (12.3)	
Quadriceps	1 (5.6)	0 (0)	
Allograft	0 (0)	1 (0.7)	
Age at index ACL reconstruction, y	20.3 ± 3.4	21.7 ± 4.5	.21
Time from ACL injury to reconstruction, mo	4.3 ± 4.8 2.8 (0.1-20.8)	6.4 ± 8.1 3.9 (0.2-58.7)	.041
Time of follow-up, mo	11.1 ± 10.0 7.6 (0.4-28.4)	19.4 ± 11.1 16.5 (2.5-46.5)	NA

Abbreviations: ACL, anterior cruciate ligament; NA, not applicable; TAS, Tegner Activity Scale.
[a]Values are mean ± SD or mean ± SD and median (range) unless otherwise indicated. For comparison between groups, Fisher's exact test (lowest 1-sided P value multiplied by 2) was used for dichotomous variables, the Mantel-Haenszel chi-square test was used for ordered categorical variables, and the Mann-Whitney U test was used for continuous variables.

TABLE 5 Postoperative Outcome in Patients With and Without a Subsequent ACL Injury[a]

	Subsequent ACL Injury (n = 18)	No Subsequent ACL Injury (n = 141)
Time to RTS, mo	10.1 ± 3.3 8.6 (7.6-19.4)	12.7 ± 4.8 11.0 (7.5-37.9)
Symmetrical muscle function[b] closest to RTS, n (%)	5 (27.8)	33 (23.4)
Quadriceps LSI, %	92.3 ± 12.1 93.2 (56.9-112.0)	95.7 ± 9.4 96.5 (74.6-121.3)

Abbreviations: ACL, anterior cruciate ligament; LSI, limb symmetry index; RTS, return to sport.
[a]Values are mean ± SD and median (range) unless otherwise indicated.
[b]All 5 tests of muscle function: LSI of 90% or greater.

why there was no association between new ACL injury and muscle function.

Our results contradict previous research that has supported a relationship between muscle function and new knee injury.[10,19] The discrepancies in results might be explained by different athlete populations (we studied a mixed group of professional and nonprofessional athletes; Kyritsis et al[19] only included male professional athletes) and by all athletes in our study having achieved an average LSI of 90% or greater (athletes in the study by Grindem et al[10] had an average LSI of between 75% and 84%). The higher LSI in our study might have been protective against a second ACL injury, and was partly explained by our criteria for patients to participate in completing the muscle function tests.

Approximately 1 in every 10 athletes in our study sustained a new ACL injury, which is lower than the proportion found in other reports.[6,26,28] Our results might be explained by the fact that the athletes were repeatedly assessed with tests of muscle function and patient-reported outcomes. Structured and progressive preoperative and postoperative rehabilitation, combined with clear goal setting and detailed patient information, may improve rehabilitation outcomes.[9]

TABLE 6 HRs Associated With a Subsequent ACL Injury (n = 159)

		Univariable Analysis		
Value	**Event Rate**	**HR of Subsequent Injury[a]**	***P* Value**	**Generalized R^2**
Patient sex		0.69 (0.27, 1.77)	.44	0.004
Female	8.6			
Male	6.0			
Height (cm), HR per 10 units		0.96 (0.91, 1.01)	.14	0.014
150-<171	8.1			
171-<179	8.8			
179-200	5.2			
Weight (kg), HR per 10 units		0.97 (0.93, 1.01)	.19	0.012
45-<66	7.2			
66-<76	9.4			
76-115	4.2			
Age at index operation (y), HR per 1 unit		0.91 (0.81, 1.03)	.13	0.016
15.2-<18.5	7.5			
18.5-<23.8	12.8			
23.8-29.9	2.3			
Time to surgery (mo), HR per 1 unit		0.93 (0.82, 1.07)	.32	0.010
0.1-<3.0	11.5			
3.0-<5.1	5.2			
5.1-58.7	5.0			
Preinjury TAS score		2.09 (1.22, 3.56)	.007	0.052
6	0.0			
7	5.4			
8	3.7			
9	6.0			
10	24.4			
Time to RTS (mo), HR per 1 unit		0.15 (0.06, 0.39)	<.001	0.088
8-<9	24.8			
9-<38	3.9			
Symmetrical muscle function		1.31 (0.47, 3.67)	.61	0.002
No	6.9			
Yes	9.0			
Quadriceps LSI (%), HR per 10 units		0.96 (0.92, 1.01)	.15	0.013
57-<90	7.7			
90-121	6.7			

Abbreviations: ACL, anterior cruciate ligament; HR, hazard ratio; LSI, limb symmetry index; RTS, return to sport; TAS, Tegner Activity Scale.
[a]*Values in parentheses are 95% confidence interval.*

Patient Demographics

Higher preinjury physical activity level was associated with a higher rate of subsequent ACL injury. Our results support previous research[10] in which patients returning to level 1 sport (eg, soccer and team handball) had a 4-fold increase in the risk of a subsequent knee injury compared with those who did not participate in level 1 sport (29.7% versus 6.9%). In the present study, the rate of second ACL injury was approximately 25% in athletes with a preinjury Tegner Activity Scale score of 10, which is in accordance with previous studies.[2,8,16,22,26,28]

Younger age has been reported as a risk factor for subsequent ACL injury.[10,20] We did not find an association between second ACL injury and patient demographics. This may be because we studied a young group of patients, and the rate of new ACL injuries was low.

Limitations

Only one third of the 494 eligible athletes responded to the study-specific questionnaire and had attended a follow-up of muscle function testing close to the time of return to sport. New ACL injuries were diagnosed clinically by the responsible physical therapist or orthopaedic surgeon. Because magnetic resonance imaging verification of injury was not mandatory, some ACL injuries might have been missed. The mean follow-up time of 15.5 months to record second ACL injury must be considered as short. In addition, time to return to sport was collected retrospectively, meaning that there is a risk of recall bias.

We defined return to sport as the first time of returning to knee-strenuous sport. Therefore, data relating to exposure were lacking—we did not know the frequency of participation, or whether the athlete participated in modified or unrestricted training/competition. Time 0 was set to return to sport, defined as a Tegner Activity Scale score of level 6 or above, and none of the eligible athletes sustained a second ACL injury prior to return to sport, which eliminates the risk of immortal time bias. Therefore, the use of the Tegner Activity Scale (level 6 or above) may be an appropriate proxy for the risk exposure for ACL injury.

A comparison analysis of demographics between athletes with complete data and those lost to follow-up revealed no significant differences, except for the time between ACL injury and ACL reconstruction. There is no reason to believe that this influenced the results. However, we cannot rule out bias in the results due to unmeasured factors.

We used 2 different modes of strength testing (isometric and isokinetic). As previous studies have demonstrated a moderate to high correlation between isometric and isokinetic tests of knee strength,[14,18] we suggest that using results from 2 different tests had no or only minor influence on the conclusions drawn. We did not account for other factors that might further explain the risk of second ACL injury, such as differences in rehabilitation protocols, surgical techniques of ACL reconstruction, the treatment of concomitant injuries, contextual and social factors, and psychological factors.

CONCLUSION

Returning to knee-strenuous sport before 9 months after ACL reconstruction was associated with a 7-fold increased rate of sustaining a second ACL injury. Achieving symmetrical muscle function or quadriceps strength was not associated with new ACL injury in young athletes. ◉

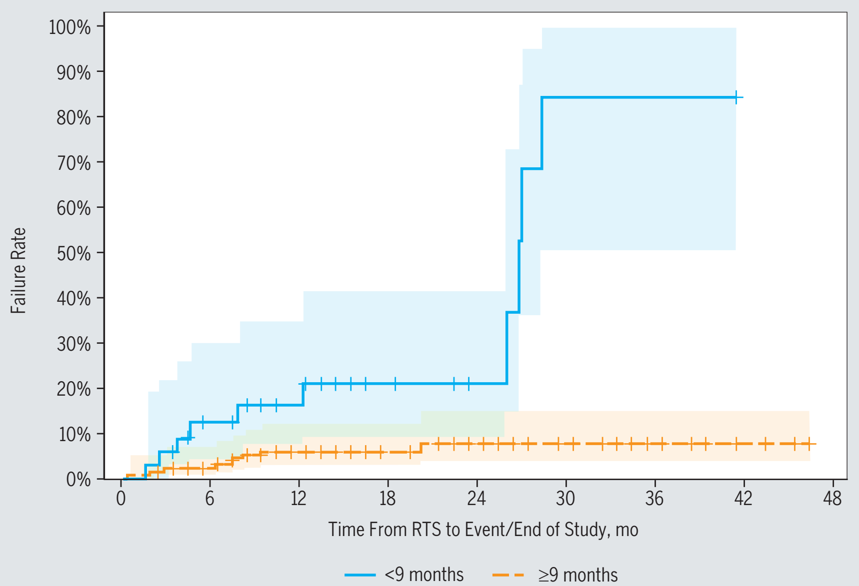

FIGURE 2. Kaplan-Meier curve showing the failure rate (rate of subsequent anterior cruciate ligament injury) in athletes after anterior cruciate ligament reconstruction who returned to knee-strenuous sport, prior to 9 months and at 9 months or after. Plus signs represent censored data. The numbers of patients at risk for each group at each time point from RTS to an event/end of study are as follows: those who returned less than 9 months after reconstruction: 0 months, n = 33; 6 months, n = 24; 12 months, n = 18; 18 months, n = 9; 24 months, n = 5; 30 months, n = 1; 36 months, n = 1; 42 months, n = 0 and those who returned at or later than 9 months after reconstruction: 0 months, n = 126; 6 months, n = 112; 12 months, n = 91; 18 months, n = 64; 24 months, n = 41; 30 months, n = 27; 36 months, n = 12; 42 months, n = 5; 48 months, n = 0. Abbreviation: RTS, return to sport.

KEY POINTS

FINDINGS: The rate of a subsequent anterior cruciate ligament (ACL) injury was approximately 7 times higher in athletes who returned to knee-strenuous sport earlier than 9 months after ACL reconstruction compared with athletes who returned to sport at or later than 9 months. There were no associations between sustaining a subsequent ACL injury and achieving symmetrical muscle function or quadriceps strength.

IMPLICATIONS: Clinicians should inform young athletes who undergo ACL reconstruction that delaying return to knee-strenuous sport until at least 9 months after ACL reconstruction confers a reduction in subsequent ACL injury rate.

CAUTION: This study only included 18 athletes who sustained a subsequent ACL injury, which limited the opportunities for in-depth analyses and assessment of multiple risk factors. The nonsignificant association between achieving symmetrical muscle function and a subsequent ACL injury may be attributed to low statistical power and to the fact that 68% of the athletes had missing data from the muscle function tests.

ACKNOWLEDGMENTS: *The authors thank biostatisticians Bengt Bengtsson and Nils-Gunnar Pehrsson from Statistiska Konsultgruppen for help with statistical analyses.*

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors contributed to project planning. Drs Beischer, Hamrin Senorski, and Thomeé and Ms Gustavsson and Mr Thomeé acquired the data. Drs Beischer, Hamrin Senorski, and Thomeé and Ms Gustavsson interpreted data. Dr Beischer and Ms Gustavsson drafted the manuscript. All authors critically revised the manuscript and approved the final version.

DATA SHARING: Individual participant data that underlie the results reported in this article (text, tables, figures, and appendix) are available, after deidentification, for researchers who provide a methodologically sound proposal. Proposals should be directed to the corresponding author.

PATIENT AND PUBLIC INVOLVEMENT: The patients and the public were not involved as research partners.

REFERENCES

1. Almosnino S, Stevenson JM, Bardana DD, Diaconescu ED, Dvir Z. Reproducibility of isokinetic knee eccentric and concentric strength indices in asymptomatic young adults. *Phys Ther Sport*. 2012;13:156-162. https://doi.org/10.1016/j.ptsp.2011.09.002
2. Andernord D, Desai N, Björnsson H, Ylander M, Karlsson J, Samuelsson K. Patient predictors of early revision surgery after anterior cruciate ligament reconstruction: a cohort study of 16,930 patients with 2-year follow-up. *Am J Sports Med*. 2015;43:121-127. https://doi.org/10.1177/0363546514552788
3. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med*. 2014;48:1543-1552. https://doi.org/10.1136/bjsports-2013-093398
4. Beischer S, Hamrin Senorski E, Thomeé C, Samuelsson K, Thomeé R. Young athletes return too early to knee-strenuous sport, without acceptable knee function after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:1966-1974. https://doi.org/10.1007/s00167-017-4747-8
5. Concato J, Feinstein AR. Monte Carlo methods in clinical research: applications in multivariable analysis. *J Investig Med*. 1997;45:394-400.
6. Dekker TJ, Godin JA, Dale KM, Garrett WE, Taylor DC, Riboh JC. Return to sport after pediatric anterior cruciate ligament reconstruction and its effect on subsequent anterior cruciate ligament injury. *J Bone Joint Surg Am*. 2017;99:897-904. https://doi.org/10.2106/JBJS.16.00758
7. Drouin JM, Valovich-McLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and validity of the Biodex System 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol*. 2004;91:22-29. https://doi.org/10.1007/s00421-003-0933-0
8. Fältström A, Hägglund M, Magnusson H, Forssblad M, Kvist J. Predictors for additional anterior cruciate ligament reconstruction: data from the Swedish national ACL register. *Knee Surg Sports Traumatol Arthrosc*. 2016;24:885-894. https://doi.org/10.1007/s00167-014-3406-6
9. Grindem H, Risberg MA, Eitzen I. Two factors that may underpin outstanding outcomes after ACL rehabilitation. *Br J Sports Med*. 2015;49:1425. https://doi.org/10.1136/bjsports-2015-095194
10. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2016;50:804-808. https://doi.org/10.1136/bjsports-2016-096031
11. Gustavsson A, Neeter C, Thomeé P, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2006;14:778-788. https://doi.org/10.1007/s00167-006-0045-6
12. Hamrin Senorski E, Samuelsson K, Thomeé C, Beischer S, Karlsson J, Thomeé R. Return to knee-strenuous sport after anterior cruciate ligament reconstruction: a report from a rehabilitation outcome registry of patient characteristics. *Knee Surg Sports Traumatol Arthrosc*. 2017;25:1364-1374. https://doi.org/10.1007/s00167-016-4280-1
13. Hamrin Senorski E, Svantesson E, Beischer S, et al. Concomitant injuries may not reduce the likelihood of achieving symmetrical muscle function one year after anterior cruciate ligament reconstruction: a prospective observational study based on 263 patients. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:2966-2977. https://doi.org/10.1007/s00167-018-4845-2
14. Harbo T, Brincks J, Andersen H. Maximal isokinetic and isometric muscle strength of major muscle groups related to age, body mass, height, and sex in 178 healthy subjects. *Eur J Appl Physiol*. 2012;112:267-275. https://doi.org/10.1007/s00421-011-1975-3
15. Ithurburn MP, Longfellow MA, Thomas S, Paterno MV, Schmitt LC. Knee function, strength, and resumption of preinjury sports participation in young athletes following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2019;49:145-153. https://doi.org/10.2519/jospt.2019.8624
16. Kaeding CC, Pedroza AD, Reinke EK, Huston LJ, MOON Consortium, Spindler KP. Risk factors and predictors of subsequent ACL injury in either knee after ACL reconstruction: prospective analysis of 2488 primary ACL reconstructions from the MOON Cohort. *Am J Sports Med*. 2015;43:1583-1590. https://doi.org/10.1177/0363546515578836
17. Kay J, Memon M, Marx RG, Peterson D, Simunovic N, Ayeni OR. Over 90 % of children and adolescents return to sport after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:1019-1036. https://doi.org/10.1007/s00167-018-4830-9
18. Knezevic OM, Mirkov DM, Kadija M, Milovanovic D, Jaric S. Evaluation of isokinetic and isometric strength measures for monitoring muscle function recovery after anterior cruciate ligament reconstruction. *J Strength Cond Res*. 2014;28:1722-1731. https://doi.org/10.1519/JSC.0000000000000307
19. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med*. 2016;50:946-951. https://doi.org/10.1136/bjsports-2015-095908
20. Nagelli CV, Hewett TE. Should return to sport be delayed until 2 years after anterior cruciate ligament reconstruction? Biological and functional considerations. *Sports Med*. 2017;47:221-232. https://doi.org/10.1007/s40279-016-0584-z
21. Ruschel C, Haupenthal A, Jacomel GF, et al. Validity and reliability of an instrumented leg-extension machine for measuring isometric muscle strength of the knee extensors. *J Sport Rehabil*. 2015;24:0122. https://doi.org/10.1123/jsr.2013-0122
22. Shelbourne KD, Gray T, Haro M. Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med*. 2009;37:246-251. https://doi.org/10.1177/0363546508325665
23. Sole G, Hamrén J, Milosavljevic S, Nicholson H, Sullivan SJ. Test-retest reliability of isokinetic knee extension and flexion. *Arch Phys Med Rehabil*. 2007;88:626-631. https://doi.org/10.1016/j.apmr.2007.02.006
24. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985:43-49.
25. Toole AR, Ithurburn MP, Rauh MJ, Hewett TE, Paterno MV, Schmitt LC. Young athletes cleared for sports participation after anterior cruciate ligament reconstruction: how many actually meet recommended return-to-sport criterion cutoffs? *J Orthop Sports Phys Ther*. 2017;47:825-833. https://doi.org/10.2519/jospt.2017.7227
26. Webster KE, Feller JA, Leigh WB, Richmond AK. Younger patients are at increased risk for graft rupture and contralateral injury after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2014;42:641-647. https://doi.org/10.1177/0363546513517540
27. Webster KE, Feller JA, Whitehead TS, Myer GD, Merory PB. Return to sport in the younger patient with anterior cruciate ligament reconstruction. *Orthop J Sports Med*. 2017;5:2325967117703399. https://doi.org/10.1177/2325967117703399
28. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44:1861-1876. https://doi.org/10.1177/0363546515621554

@ MORE INFORMATION
WWW.JOSPT.ORG

APPENDIX

HRS OF EACH OF THE INDEPENDENT VARIABLES FOR THE SENSITIVITY ANALYSES (N = 264)

			Univariable Cox Regression		
Value	Event Rate[a]	n	HR of Subsequent Injury[b]	*P* Value	Generalized R^2
Patient sex			0.61 (0.24, 1.53)	.29	0.004
Female	5.6	140			
Male	3.4	124			
Height (cm), HR per 10 units			0.95 (0.91, 1.00)	.043	0.014
150-<171	6.0	95			
171-<179	4.9	81			
179-200	2.8	87			
Weight (kg), HR per 10 units			0.96 (0.92, 1.00)	.069	0.012
45-<66	5.8	75			
66-<76	5.6	85			
76-115	2.3	79			
Age at index operation (y), HR per 1 unit			0.92 (0.82, 1.03)	.13	0.016
15.2-<18.5	3.9	89			
18.5-<24.2	7.6	93			
24.2-29.9	1.5	77			
Time to surgery (mo), HR per 1 unit			0.91 (0.79, 1.04)	.16	0.010
0.1-<3.0	7.2	90			
3.0-<5.1	4.3	75			
5.1-<58.7	2.4	98			
Preinjury TAS score			2.01 (1.20, 3.36)	.008	0.052
6	0.0	13			
7	3.6	30			
8	2.3	69			
9	3.7	102			
10	14.0	50			
Time to RTS (mo), HR per 1 unit			0.37 (0.15, 0.89)	.027	0.088
8-<9	7.9	81			
9-<38	3.0	183			
Symmetrical muscle function			1.31 (0.47, 3.67)	.61	0.002
No	6.9	121			
Yes	9.0	38			
Quadriceps strength LSI (%), HR per 10 units			0.96 (0.92, 1.01)	.14	0.013
57-<90	7.7	42			
90-121	6.7	118			

Abbreviations: HR, hazard ratio; LSI, limb symmetry index; RTS, return to sport; TAS, Tegner Activity Scale.
[a]*Per observed 100 patient-years.*
[b]*Values in parentheses are 95% confidence interval.*

CORRIGENDUM

In the February 2020 issue of the *JOSPT*, the article "Young Athletes Who Return to Sport Before 9 Months After Anterior Cruciate Ligament Reconstruction Have a Rate of New Injury 7 Times That of Those Who Delay Return" erroneously reported that females were 64% of the total sample. When the data were extracted again, the authors found that 22 participants (total sample, n = 159) had been misclassified as females, making the actual percentage of females 50%. The text, **TABLES 4** and **6**, and the **APPENDIX** have been corrected to reflect this finding. The updated article is available at *www.jospt.org*.

CHRIS BLEAKLEY, PhD[1,2] • JONATHAN REIJGERS, BSc[2] • JAMES M. SMOLIGA, PhD[2]

Many High-Quality Randomized Controlled Trials in Sports Physical Therapy Are Making False-Positive Claims of Treatment Effect: A Systematic Survey

High-quality research can help clinicians and patients decide which treatments are likely to be most effective.[15] Replication of research findings is an integral part of the scientific process, and represents a more robust evidence base for clinical decision making. However, there is concern that the majority of published research claims are false.[17]

In a survey of 1576 researchers, more than 70% had tried and failed to reproduce another scientist's experiment, and more than half failed to reproduce their own experiments.[1] In preclinical research, only 11% to 49% of research findings have been successfully replicated,[10] with similar figures reported in psychological science.[27] Although evidence-based practice should substantially improve the quality and cost of health care, serious concerns regarding randomized controlled trial (RCT) design and statistical analysis raise questions about the validity of evidence-based interventions.

OBJECTIVE: To examine the risk of false-positive reporting within high-quality randomized controlled trials (RCTs) in the sports physical therapy field.

DESIGN: Cross-sectional.

METHODS: We searched the Physiotherapy Evidence Database for parallel-design, 2-arm RCTs reporting positive treatment effects, based on null-hypothesis significance testing, and scoring greater than 6/10 on the Physiotherapy Evidence Database scale. No restrictions were made on pathology, intervention, or outcome variables. Sixty-two of 212 RCTs reported positive effects in at least 1 outcome variable. We estimated false-positive risk (FPR) with an online calculator, based on number of participants, *P* value, and effect size. For each study, FPR was estimated using a range of prior probability assumptions: 0.2 (skeptical hypothesis), 0.5, and 0.8 (optimistic hypothesis).

RESULTS: We calculated the FPR associated with 189 statistically significant findings (*P*<.05) reported across 44 trials. The median FPR was 9% (25th-75th percentile, 2%-24%). Sixty-three percent of statistically significant results (119/189) had an FPR greater than 5%, and 18% (35/189) had an FPR greater than 50%. Changing the prior probability from skeptical to optimistic reduced the median FPR from 29% (25th-75th percentile, 9%-56%) to 2% (25th-75th percentile, 0.6%-7.0%).

CONCLUSION: High-quality RCTs using null-hypothesis significance testing often overestimated treatment effects. The median FPR was 9%: in 1 in 10 trials, the researchers falsely concluded that there was a treatment effect. Future RCTs in sports physical therapy should be informed by prestudy odds and a minimum FPR estimation. *J Orthop Sports Phys Ther 2020;50(2):104-109. doi:10.2519/jospt.2020.9264*

KEY WORDS: *false-positive risk, null-hypothesis significance testing, P values, randomized controlled trials*

Statistical analysis in medical research is usually frequentist: conclusions informed by *P* (probability) values generated from null-hypothesis significance testing. However, many researchers and clinicians are unable to define or accurately interpret *P* values.[6] Common misconceptions are that a *P* value represents "the probability that the results occurred by chance" or "the probability that the null hypothesis (H0) is true"[6] or "the probability that the hypothesis being tested is true."[24] A *P* value only represents the probability that the obtained data, or more extreme values, could be obtained if the null hypothesis were true,[24] that is, the probability of the data, on the condition that the null hypothesis is true. For more help understanding *P* values, see Kamper.[18]

Misinterpreting the results of statistical tests makes it difficult to disentangle true-positive from false-positive findings. Understanding and accurately applying appropriate statistics defend against false discoveries.[24] Central to this process is quantifying the false-positive risk (FPR),

[1]School of Health Sciences, Faculty of Life and Health Sciences, Ulster University, Newtownabbey, United Kingdom. [2]Department of Physical Therapy, Congdon School of Health Sciences, High Point University, High Point, NC. No funding was received for this study. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Chris Bleakley, School of Health Sciences, Faculty of Life and Health Sciences, Ulster University, Newtownabbey BT370QB United Kingdom. E-mail: c.bleakley@ulster.ac.uk

"the probability of observing a statistically significant *p*-value and declaring that an effect is real, when it is not."[4] The FPR within different areas of biomedical science has been conservatively estimated at 25%.[24] This means that in at least 1 in 4 studies, the researchers falsely concluded that a treatment effect had occurred. Others[5,6,17] have used data simulations to demonstrate that experimental studies can carry a high FPR, even if their effect sizes are large and/or *P* values are less than commonly used thresholds such as $P<.01$.

The issue of irreproducible data has been discussed by scientists for decades.[2] However, it has received little attention in health care. No one has examined FPR using primary data extracted from high-quality clinical experimental research. Given the criticism of a weak evidence base for orthopaedics and sports medicine,[3,14,22,26] our objective was to estimate the FPR of high-quality RCTs in sports physical therapy. Our secondary objectives were to examine the relationship between FPR and reported *P* values by quantifying the number of studies with an FPR greater than 5%, and to determine how FPR changed based on assumptions around the prior probability of effect.

METHODS

Trial Selection

Trials were sourced from the Physiotherapy Evidence Database (PEDro), a freely accessible database to "guide users to trials that are more likely to be valid" and "guide clinical practice."[19] In addition to serving as a database for clinical trials, PEDro includes a 10-item scale quantifying study quality.[7,14]

We identified all RCTs scoring greater than 6/10 and categorized in the subcategory of "sports," defined by PEDro as "papers which specifically mention sports injuries as well as conditions which commonly affect sports people (eg, ligament repairs)." Eligible RCTs must have employed null-hypothesis significance testing to determine evidence of effect and used a parallel-group design. No restrictions were made on pathology, intervention type, or date of publication. We excluded RCTs with healthy participants only, greater than 2 intervention groups, and crossover, cluster, or pilot study designs.

Data Extraction and Management

We extracted the following data from all eligible trials: population, number of participants, primary diagnosis, intervention, comparison, outcome(s), allocation ratio, follow-up time, *P* value, effect size, trial registration number, and a priori power calculation.

We subgrouped the trials as either (1) positive, reporting a dichotomous threshold of statistical significance ($P<.05$) in at least 1 outcome; or (2) null, reporting no evidence of effect ($P>.05$).

For all trials that reported evidence of effect (positive studies), we extracted additional data. First, we extracted details of between-group comparisons, making no restriction on outcome construct or follow-up time. If there was a between-group comparison with a positive statistically significant finding, we extracted the *P* value and the number of participants in each group, and, when possible, calculated the corresponding effect size (Hedges' *g*). If a trial reported a threshold of $P<.05$, rather than an exact *P* value, we assumed that the *P* value was one hundredth below the threshold value (eg, .049).

Estimating the FPR

We calculated FPR using an online calculator.[23] For further details of the analysis script and simulated examples of FPR calculations, see Colquhoun.[4,6] Calculating FPR requires imputation of the prior probability that there is a real effect, P(H1), for a given treatment. In all trials, we initially assumed that P(H1) was 0.5—that there was a 50% probability that a treatment intervention had a positive underlying effect before the trial was conducted.[5,6]

We ran additional simulations based on extreme prior probabilities of P(H1) = 0.2, where the chances of a positive effect are very small (a skeptical hypothesis), and P(H1) = 0.8, where chances of a positive effect are almost certain (an optimistic hypothesis). We also applied a reverse Bayesian approach[6,25] using observed *P* values to determine the prior probability that would be required to achieve an FPR of 5%. In all cases, FPR estimations were calculated using the *P*-equals method,[23] which is the probability of observing a statistically significant finding that is due to chance for a single result, rather than trying to estimate the long-term error rate (lifetime FPR).

We calculated FPR for primary and secondary outcomes where applicable. When trials included multiple outcome measures but did not clearly specify a primary outcome, we assigned a primary outcome based on the nature of the research question and the following definition[28]: "a specific key measurement(s) or observation(s) used to measure the effect of experimental variables in a study." We examined the relationship between all reported *P* values and the corresponding FPR using descriptive statistics and scatter and violin plots.

RESULTS

In the PEDro subcategory of sports, we identified 212 RCTs with a score of greater than 6/10 on the PEDro scale. Of these, 90 were excluded for the following reasons: not being a parallel-design (2-group) RCT (n = 56), including only healthy participants (no clinical outcomes) (n = 23), not being in the English language (n = 9), and not having an available abstract or full text (n = 2).

Of the 122 included RCTs, 49% (n = 60) reported a null finding and 51% (n = 62) reported positive effects from at least 1 outcome (**FIGURE 1**). Full trial details for the 62 studies that reported positive effects can be found in the **SUPPLEMENTARY DATA FILE** (available at www.jospt.org). There were few differences between the subgroups (positive versus null) in primary diagnoses and treatment interventions

(**FIGURE 1**). The majority of RCTs included participants with tendinopathy (47 studies), musculoskeletal pain (19 studies), or ligament/joint problems (21 studies). Electrophysical agents (48 studies), rehabilitation (37 studies), and manual therapy (17 studies) were the most common interventions.

False-Positive Risk

Of the trials reporting positive effects (n = 62), 67% compared 2 different physiotherapeutic approaches and 33% used either sham or placebo controls. The mean ± SD sample size was 57.3 ± 35.2 (range, 16-172). Twenty-nine percent of trials (18/62) were prospectively registered, and 64% (40/62) reported using a priori sample-size calculation. The majority of sample-size estimations included alpha (type I error) and beta (type II error) levels of 5% and 20%, respectively, and the anticipated a priori effect size used was 0.9 ± 0.4 (range, 0.2- 2.2).

We could not calculate FPR in 18 trials due to missing data. In the remaining 44 trials, we calculated FPR associated with 189 between-group comparisons reported as statistically significant. Lower *P* values were associated with lower FPR (**FIGURE 2**). The mean ± SD FPR (based on prior probability of 0.5) was 25.2% ± 34.3%. As the data were not normally distributed, the median FPR of 9% was more representative of the data's central tendency (25th-75th percentile, 2%-24%). Sixty-three percent of reported *P* values (119/189) were associated with FPRs greater than 5%, and 18% (35/189) had an FPR greater than 50%.

Using a reverse Bayesian approach, 57% (68/119) of statistically significant findings (primary or secondary outcomes) would require prior probabilities greater than 0.8 if FPRs of 5% were to be achieved. False-positive risk patterns were similar when examining only primary outcomes, with mean and median FPRs of 22.9% ± 36.1% and 5% (25th-75th percentile, 1%-22%), respectively.

The lowest FPR occurred when the prior probability of effect was assumed to be 0.8, with a median risk of 2% (25th-75th percentile, 0.6%-7.0%) (**FIGURE 3**). False-positive risk increased when prior probabilities of 0.2 were assumed (median risk, 29%; 25th-75th percentile, 9%-56%).

DISCUSSION

We found that 63% of statistically significant findings (*P*<.05) in the sports physical therapy literature generated FPRs greater than 5%. Repeated simulations of *t* tests suggest that if one uses *P* = .05 to conclude a discovery, one will be wrong at least 30% of the time.[5] False discoveries (claiming a treatment effect is real when it isn't) may be minimized through better understanding of the FPR. This is the first time that the health care literature has been audited to determine the FPR using primary data extracted from higher-quality clinical experimental research. The median FPR was 9% (25th-75th percentile, 2%-24%), suggesting that approximately 1 in every 10 trials in the sports physical therapy field have falsely concluded a treatment effect.

There have been a range of proposals to help minimize unsubstantiated claims of effectiveness in research. One option

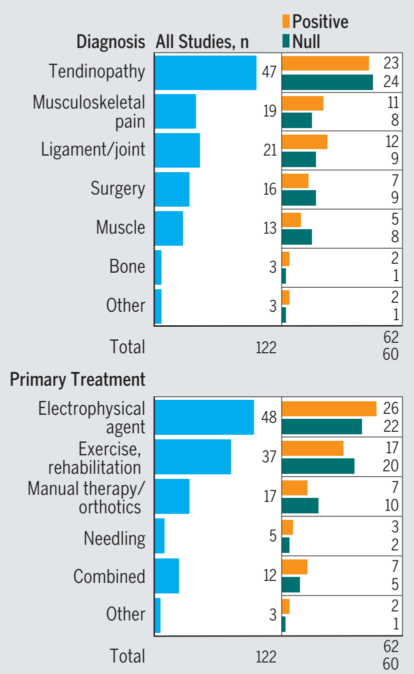

FIGURE 1. Diagnosis and primary treatment.

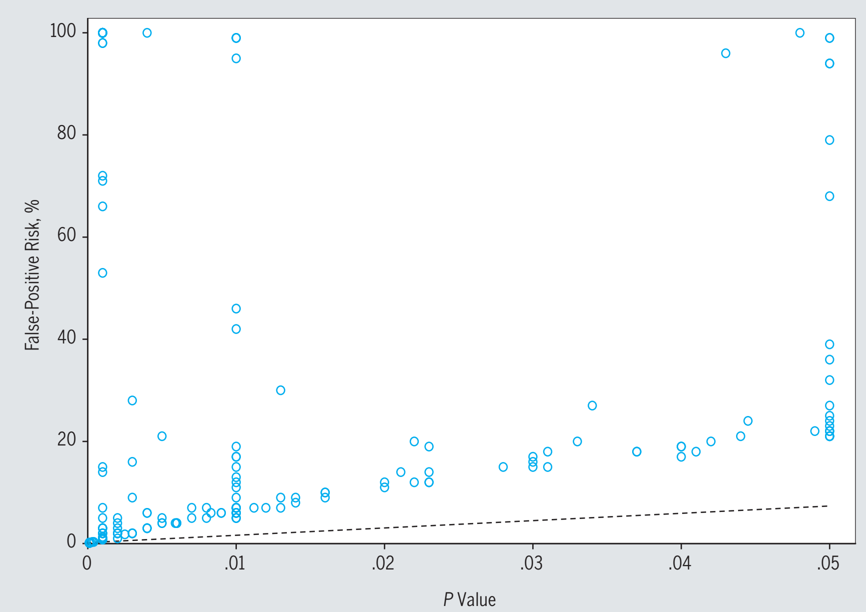

FIGURE 2. *P* value versus false-positive risk. Data relate to 189 positive effects reported from high-quality randomized controlled trials (n = 44). False-positive risk is based on a prior probability of 0.5. The dashed line is the reference (when the *P* value is equal to the false-positive risk).

has been to lower P value thresholds to $P \leq .001$ to keep false-discovery rates below 5%.[5] Recently, the American Statistical Association released a number of recommendations aimed at improving use of null-hypothesis significance testing.[32] The core objective of the American Statistical Association is to progress research beyond "all or nothing" hypothesis tests, which may be particularly important if the theoretical predictions within a study are weak.[30]

Clinical decisions should not be made solely on a P value.[32] Many of the positive statistically significant conclusions from high-quality RCTs in sports physical therapy are probably no more than suggestive. Researchers must also understand that null-hypothesis significance testing is only designed to work efficiently in the context of long-run repeated testing (exact replication).[30] A single significant result should not be concluded as a "scientific fact." The result should be interpreted as something worthy of further investigation,[12,31] particularly if it was derived from a secondary outcome.

There is no consensus on how best to communicate results of testing scientific hypotheses. Randomized controlled trials in orthopaedics and sports medicine have traditionally used a frequentist statistical approach, based on deductive inference. Our calculation of FPR involved application of Bayes' theorem, in which the central tenet is to consider how current data alter our "prior probability" to generate a new "posterior probability." We initially used a "noninformative" prior probability of 50%, meaning that we assumed even odds of treatment effect. In auditing clinical studies from a diverse field, we found hypotheses that were more skeptical or optimistic. Therefore, we calculated FPRs based on both low (P(H1) = 0.2) and high (P(H1) = 0.8) prior probabilities. As expected, when prior probabilities were shifted closer to zero, the FPR was inflated; when we assumed a high prior probability of effect, 75% of findings had FPRs less than 8%.

There is continuing debate about the relative merits of the frequentist and Bayesian approaches to statistical analysis. Our findings highlight how Bayesian thinking and conditional probabilities can affect the interpretation of null-hypothesis significance testing.[5] For example, a statistically significant finding generated from an RCT examining the effects of jugular vein compression devices[29] on concussion incidence in contact sports (skeptical prior probability) should be interpreted with more caution than a statistically significant finding from an RCT testing the analgesic effects of topical cooling after a musculoskeletal injury (optimistic prior probability). In effect, Bayesian logic ensures that the skeptical prior example requires more "extreme" data before treatment effectiveness can be concluded. In contrast, the traditional frequentist approach does not differentiate between these 2 research questions.

A key limitation of Bayes' theorem is the uncertainty when determining what a suitable prior probability should be. One solution is a reverse Bayesian approach,[25] where the observed P value is used to calculate the prior probability required to achieve a specific or minimal FPR (eg, 5%). This approach allows the researcher to determine whether the calculated prior probability is plausible. It has been suggested that 0.5 (or a 50:50 chance of success) might be the largest prior probability that can be legitimately assumed.[6] In our analysis, approximately 60% of positive (statistically significant, $P<.05$) outcomes would require prior probabilities greater than 0.8 to achieve FPRs of 5%. Such extreme prior probabilities are likely unacceptable, as they represent situations in which a researcher may be almost certain of treatment success (a nonzero effect) before the experiment is even initiated.

Trials with positive outcomes are published more often, and more quickly, than trials with negative findings.[16] The proportion of positive results in published scientific literature may be as high as 86%.[9] In our analysis of high-quality RCTs within sports physical therapy, we found an equal ratio of trials reporting positive and null effects. Although this might suggest that publication bias is not an issue within the sports physical therapy field, there were no trials reporting negative or harmful effects of an intervention. There may also be publication bias in lower-quality studies, which we excluded. Trial registration is considered an effective way to control publication

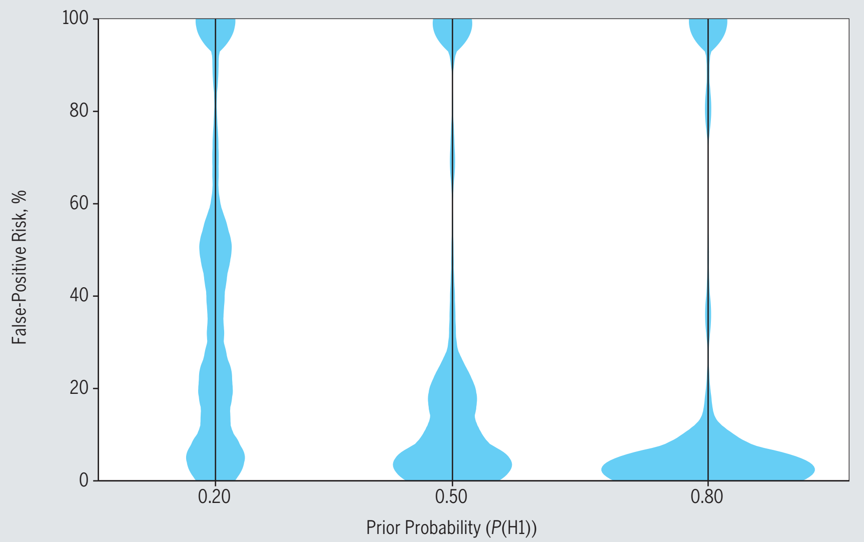

FIGURE 3. False-positive risk based on 3 different prior probability levels: P(H1) = 0.2, P(H1) = 0.5, and P(H1) = 0.8. In all calculations, data relate to 189 positive effects reported from high-quality randomized controlled trials (n = 44).

bias,[20] and can help to prevent cherry picking statistically significant results later. We found that only 29% of sports physical therapy trials were prospectively registered. It is important that this figure eventually increase to 100%. A broader and more complex challenge is that often, many trials have discord between the original registry data and the published data, despite registration.[11] Additional solutions have been proposed, including improved Consolidated Standards of Reporting Trials compliance from both researchers and editorial boards and improvement to the postpublication peer-review process.[11]

The evidence base for orthopaedics and sports medicine has been criticized for inappropriate participant selection[3] and high risk of bias.[22] Issues related to undefined primary end points and multiple comparisons have plagued the literature,[22] but their relevance has been difficult to quantify. Our results suggest that methodological shortcomings may be leading researchers in orthopaedics, sports medicine, and sports physical therapy astray in their conclusions and negatively influencing evidence-based practice.

Limitations

A recent audit of PEDro listed more than 23 049 RCTs, of which 1098 have been undertaken in sports-related disciplines.[19] We limited inclusion to RCTs archived within PEDro and used a cutoff of greater than 6/10 (on the PEDro scale) to define "high quality." Our audit was limited to results from single experiments, and we did not fully consider false discoveries relating to other important sources, such as the use of multiple treatment arms, analysis of multiple outcomes, and multiple analyses of the same outcome at different times.[21] False-positive risk is likely to increase when lower-quality methodological designs are employed[6]; therefore, our FPR estimations are likely conservative in the broader context of all clinical trials. We did not focus on false-negative findings or outcomes deemed to be surrogate in nature (eg, biomarkers). We acknowledge the importance of directing future work to this area; our primary focus was on the risk of false-positive findings regarding outcomes that reflect real clinical settings.

Recommendations for Future Research

Future reports should include exact figures for P values rather than thresholds ($P<.05$) and avoid using the term *significant*.[5] We were often unable to calculate FPR due to missing data. It is essential that researchers accompany reported P values with effect sizes, corresponding confidence intervals, and, ideally, a minimum FPR estimation. It is important that there is a continued focus on mandatory preregistration of study protocols and publication of prestudy power calculations and effect sizes, including any negative findings.

While the proper use of statistics will help to minimize false discoveries in research, there are other factors currently influencing the risk of erroneous findings in the sports physical therapy field. It is possible that the existing academic system in sports physical therapy (like many other areas of health care) might increase the risk of erroneous or selective publishing, because career milestones such as promotion or tenure are often determined by the volume of researchers' publication record.[13] Journal editors, reviewers, and grant-review committees may also favor scientific findings that are confirmatory, clear, and complete,[2] limiting the chances of disseminating negative or contradictory research findings. We encourage researchers to examine FPR in other disciplines of health care.

To calculate FPR, we used an online calculator that uses post hoc statistical power to inform FPR values. It is possible that some studies recorded very large effect sizes due to sampling variation, which consequently overestimates statistical power (a posteriori) and potentially inflates the FPR estimate. Future research could include additional FPR estimations using a range of statistical power parameters (partially post hoc power).[8]

CONCLUSION

Research conclusions should not be based solely on null-hypothesis significance testing and P values. Over 60% of statistically significant findings ($P<.05$) reported in the sports physical therapy literature carried FPRs greater than 5%, and the median FPR was 9% (assuming a prior probability of 0.5).

KEY POINTS

FINDINGS: Many of the positive statistically significant conclusions from high-quality randomized controlled trials in sports physical therapy are probably no more than suggestive. We estimate the median false-positive risk in this field to be 9% (25th-75th percentile, 2%-24%).

IMPLICATIONS: Research conclusions should not be based solely on null-hypothesis significance testing and P values. The risk of making a false claim of treatment effectiveness can be reduced through more rigorous consideration of prestudy odds (ie, the chances that a treatment will work a priori) and reporting of false-positive risk (a posteriori).

CAUTION: This audit was limited to high-quality, 2-arm randomized controlled trials. We also did not consider other sources of false discoveries in research, such as the use of multiple treatment arms, analysis of multiple outcomes, and multiple analyses of the same outcome at different time points.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Drs Bleakley and Smoliga were involved in the concept, design, and writing. Dr Bleakley and Mr Reijgers were involved in the analysis. All authors were involved in final submission and revision of the manuscript.

DATA SHARING: Data sharing is not applicable to this article, as no data sets

were generated or analyzed during the current study.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient or public involvement in this article.

REFERENCES

1. Baker M. Reproducibility crisis: blame it on the antibodies. *Nature*. 2015;521:274-276. https://doi.org/10.1038/521274a
2. Begley CG, Ellis LM. Drug development: raise standards for preclinical cancer research. *Nature*. 2012;483:531-533. https://doi.org/10.1038/483531a
3. Bleakley C, MacAuley D, McDonough S. Are sports medicine journals relevant and applicable to practitioners and athletes? *Br J Sports Med*. 2004;38:E23. https://doi.org/10.1136/bjsm.2003.010553
4. Colquhoun D. The false positive risk: a proposal concerning what to do about *p*-values. *Am Stat*. 2019;73:192-201. https://doi.org/10.1080/00031305.2018.1529622
5. Colquhoun D. An investigation of the false discovery rate and the misinterpretation of *p*-values. *R Soc Open Sci*. 2014;1:140216. https://doi.org/10.1098/rsos.140216
6. Colquhoun D. The reproducibility of research and the misinterpretation of *p*-values. *R Soc Open Sci*. 2017;4:171085. https://doi.org/10.1098/rsos.171085
7. de Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother*. 2009;55:129-133. https://doi.org/10.1016/s0004-9514(09)70043-1
8. Dziak JJ, Dierker LC, Abar B. The interpretation of statistical power after the data have been gathered. *Curr Psychol*. In press. https://doi.org/10.1007/s12144-018-0018-1
9. Fanelli D. Negative results are disappearing from most disciplines and countries. *Scientometrics*. 2012;90:891-904. https://doi.org/10.1007/s11192-011-0494-7
10. Freedman LP, Cockburn IM, Simcoe TS. The economics of reproducibility in preclinical research. *PLoS Biol*. 2015;13:e1002165. https://doi.org/10.1371/journal.pbio.1002165
11. Goldacre B, Drysdale H, Dale A, et al. COMPare: a prospective cohort study correcting and monitoring 58 misreported trials in real time. *Trials*. 2019;20:118. https://doi.org/10.1186/s13063-019-3173-2
12. Goodman S. A dirty dozen: twelve *P*-value misconceptions. *Semin Hematol*. 2008;45:135-140. https://doi.org/10.1053/j.seminhematol.2008.04.003
13. Grimes DR, Bauch CT, Ioannidis JPA. Modelling science trustworthiness under publish or perish pressure. *R Soc Open Sci*. 2018;5:171511. https://doi.org/10.1098/rsos.171511
14. Harris JD, Cvetanovich G, Erickson BJ, et al. Current status of evidence-based sports medicine. *Arthroscopy*. 2014;30:362-371. https://doi.org/10.1016/j.arthro.2013.11.015
15. Heneghan C, Goldacre B, Mahtani KR. Why clinical trial outcomes fail to translate into benefits for patients. *Trials*. 2017;18:122. https://doi.org/10.1186/s13063-017-1870-2
16. Hopewell S, Loudon K, Clarke MJ, Oxman AD, Dickersin K. Publication bias in clinical trials due to statistical significance or direction of trial results. *Cochrane Database Syst Rev*. 2009:MR000006. https://doi.org/10.1002/14651858.MR000006.pub3
17. Ioannidis JP. Why most published research findings are false. *PLoS Med*. 2005;2:e124. https://doi.org/10.1371/journal.pmed.0020124
18. Kamper SJ. Interpreting outcomes 2—statistical significance and clinical meaningfulness: linking evidence to practice. *J Orthop Sports Phys Ther*. 2019;49:559-560. https://doi.org/10.2519/jospt.2019.0704
19. Kamper SJ, Moseley AM, Herbert RD, Maher CG, Elkins MR, Sherrington C. 15 years of tracking physiotherapy evidence on PEDro, where are we now? *Br J Sports Med*. 2015;49:907-909. https://doi.org/10.1136/bjsports-2014-094468
20. Laine C, Horton R, DeAngelis CD, et al. Clinical trial registration: looking back and moving ahead. *Lancet*. 2007;369:1909-1911. https://doi.org/10.1016/S0140-6736(07)60894-0
21. Li G, Taljaard M, Van den Heuvel ER, et al. An introduction to multiplicity issues in clinical trials: the what, why, when and how. *Int J Epidemiol*. 2017;46:746-755. https://doi.org/10.1093/ije/dyw320
22. Lohmander LS, Roos EM. The evidence base for orthopaedics and sports medicine. *BMJ*. 2015;350:g7835. https://doi.org/10.1136/bmj.g7835
23. Longstaff C, Colquhoun D. Calculator for False Positive Risk. Available at: http://fpr-calc.ucl.ac.uk/. Accessed January 2, 2019.
24. Marino MJ. How often should we expect to be wrong? Statistical power, P values, and the expected prevalence of false discoveries. *Biochem Pharmacol*. 2018;151:226-233. https://doi.org/10.1016/j.bcp.2017.12.011
25. Matthews RAJ. Why *should* clinicians care about Bayesian methods? *J Stat Plan Inference*. 2001;94:43-58. https://doi.org/10.1016/S0378-3758(00)00232-9
26. Moseley AM, Elkins MR, Janer-Duncan L, Hush JM. The quality of reports of randomized controlled trials varies between subdisciplines of physiotherapy. *Physiother Can*. 2014;66:36-43. https://doi.org/10.3138/ptc.2012-68
27. Open Science Collaboration. Estimating the reproducibility of psychological science. *Science*. 2015;349:aac4716. https://doi.org/10.1126/science.aac4716
28. Ramagopalan S, Skingsley AP, Handunnetthi L, et al. Prevalence of primary outcome changes in clinical trials registered on ClinicalTrials.gov: a cross-sectional study. *F1000Res*. 2014;3:77. https://doi.org/10.12688/f1000research.3784.1
29. Smoliga JM, Wang L. Woodpeckers don't play football: implications for novel brain protection devices using mild jugular compression. *Br J Sports Med*. 2019;53:1262-1263. https://doi.org/10.1136/bjsports-2018-099594
30. Szucs D, Ioannidis JPA. When null hypothesis significance testing is unsuitable for research: a reassessment. *Front Hum Neurosci*. 2017;11:390. https://doi.org/10.3389/fnhum.2017.00390
31. Wood J, Freemantle N, King M, Nazareth I. Trap of trends to statistical significance: likelihood of near significant P value becoming more significant with extra data. *BMJ*. 2014;348:g2215. https://doi.org/10.1136/bmj.g2215
32. Yaddanapudi LN. The American Statistical Association statement on *P*-values explained. *J Anaesthesiol Clin Pharmacol*. 2016;32:421-423. https://doi.org/10.4103/0970-9185.194772

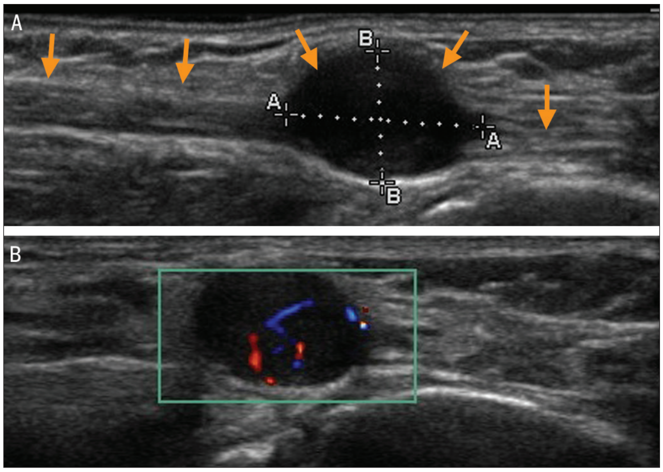

FIGURE 1. (A) Long-axis view of the posterior tibial nerve (arrows) showing the nerve tumor as a hypoechoic soft tissue mass within the nerve sheath. (B) Oblique short-axis view of the soft tissue mass showing vascularity on color Doppler ultrasound.

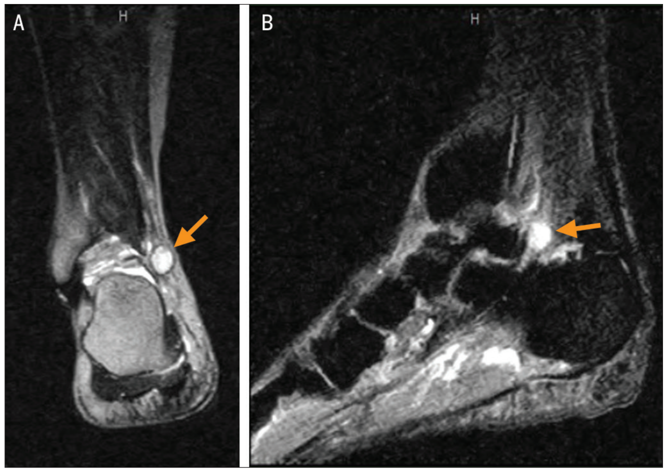

FIGURE 2. (A) Coronal, T2-weighted, fast spin-echo magnetic resonance image of the ankle showing the nerve tumor (arrow). (B) Sagittal, short-tau inversion recovery magnetic resonance image showing the nerve tumor (arrow).

Schwannoma of the Posterior Tibial Nerve

VICKI BUCHANAN, PT, BS, FMSK, *Regional Physical Therapy, Inc, Midwest City, OK.*
MOHINI RAWAT, DPT, MS, ECS, OCS, RMSK, *Hands-on Diagnostics, Astoria, NY.*

A 61-YEAR-OLD WOMAN WAS REferred to physical therapy by a podiatrist who suspected a posterior tibialis degenerative tear. Previously, the patient had been walking 4 miles a day for the past 3 years. Pain at the right medial ankle began insidiously 1.5 years ago and progressed to where she stopped exercising 2 months ago. Her chief complaint was activity-instigated pain in the medial ankle that radiated into the medial calf and the first 2 toes. Prior vascular ultrasound ruled out peripheral vascular disease.

Clinical examination noted an antalgic gait due to exacerbation of pain with active dorsiflexion. Manual muscle testing at the ankle was within normal limits for all muscles. Pain at the medial ankle was elicited with passive, active, and resisted motions into dorsiflexion and eversion. Tinel's test to the tarsal tunnel reproduced pain to the medial calf and toes.

To further examine the irritable posterior tibial nerve, a musculoskeletal ultrasound examination was performed, revealing a focal soft tissue mass within the posterior tibial nerve near the tarsal tunnel, showing a vascularized focal lesion suggestive of a nerve tumor (**FIGURE 1**).[1,3] The patient was referred back to the referring podiatrist, who ordered magnetic resonance imaging, which confirmed the schwannoma of the posterior tibialis nerve (**FIGURE 2**).[2] The patient had surgery to remove the schwannoma without loss of the motor portion of the nerve, preventing loss of function to the patient's foot/ankle. She returned to pain-free gait following the surgery.

Diagnosis of a posterior tibial nerve schwannoma is often delayed, as in this patient's case, as the tumor may be deep and not easily palpable. Also, neuropathic pain at the foot can be mistaken for lumbar radiculopathy in the absence of a palpable mass. Musculoskeletal ultrasound expedited this patient's diagnosis and successful treatment. ◉ *J Orthop Sports Phys Ther 2020;50(2):111. doi:10.2519/jospt.2020.9103*

References
1. Lee SJ, Yoon ST. Ultrasonographic and clinical characteristics of schwannoma of the hand. *Clin Orthop Surg*. 2017;9:91-95. https://doi.org/10.4055/cios.2017.9.1.91
2. Rajasekaran RB, Shanmuganathan R. Schwannoma of the posterior tibial nerve presenting as tarsal tunnel syndrome: a case report with emphasis on the role of microscope during surgery. *Case Rep Orthop*. 2018;2018:4704362. https://doi.org/10.1155/2018/4704362
3. Reynolds DL, Jr., Jacobson JA, Inampudi P, Jamadar DA, Ebrahim FS, Hayes CW. Sonographic characteristics of peripheral nerve sheath tumors. *AJR Am J Roentgenol*. 2004;182:741-744. https://doi.org/10.2214/ajr.182.3.1820741

[LITERATURE REVIEW]

GARRETT S. BULLOCK, PT, DPT[1,2] • JERNEJA UHAN, BSc, MSc[1,2] • ELINOR K. HARRISS[3]
NIGEL K. ARDEN, MD, FRCP[1,2] • STEPHANIE R. FILBAY, BPhty (Hons), PhD[1,2]

The Relationship Between Baseball Participation and Health: A Systematic Scoping Review

Participation in sports such as baseball may provide many physical benefits, including improved physical fitness, cardiovascular health, strength, and balance.[98,111] Despite physical health benefits of baseball participation, there is a high injury incidence at all competition levels.[69,114,128] It is unclear whether initiatives such as limiting pitch counts,[51] strength and conditioning programs,[48] and development of injury prevention and rehabilitation programs have been effective in reducing injury prevalence.[39] Baseball injuries result in increased health care costs[79] and workplace time loss,[34] and long-term physical complications such as increased risk of osteoarthritis[151] and body mass index (BMI).[151] Baseball also has a cultural history of alcohol[155] and tobacco use,[154] which can increase morbidity[93,118] and diminish longevity.[74] Currently, there is a lack of understanding of the overall health impacts of playing baseball.

OBJECTIVE: To investigate the relationship between baseball participation and health (musculoskeletal, general, and psychological health) and to identify research gaps in the existing literature.

DESIGN: Systematic scoping review.

LITERATURE SEARCH: Medical databases and gray literature were systematically searched from inception to November 2018.

STUDY SELECTION CRITERIA: All studies that investigated constructs related to the health of current or former baseball players were included.

DATA SYNTHESIS: Data were extracted for thematic summaries.

RESULTS: Ten thousand five hundred seventy-four titles/abstracts were screened, and 678 studies were included. Ninety percent of articles included only baseball players playing in the United States, 34% of articles investigated professional baseball players, and 11% studied college baseball players. Five hundred eighty-three (86%) studies investigated musculoskeletal health, 77 (11%) general health, and 18 (3%) psychological health. Injury incidence (injuries per 1000 athlete exposures) ranged from 0.7 to 3.6 in professional, 4.7 to 5.8 in college, and 0.8 to 4.0 in high school baseball. Among baseball players, 31% to 50% reported regular tobacco use. There was limited research investigating psychological health in current or former baseball players at all competition levels.

CONCLUSION: Almost 90% of all articles investigated musculoskeletal health, with few articles studying general or psychological health. Baseball players have high tobacco, alcohol, and drug use compared to the general population, which may have negative health outcomes. Little is understood about the long-term musculoskeletal, general, and psychological health of baseball players. *J Orthop Sports Phys Ther 2020;50(2):55-66. doi:10.2519/jospt.2020.9281*

KEY WORDS: *injury, mental health, quality of life*

Sport participation can have a positive impact on psychological health.[49] Psychological health encompasses multiple domains, including mental health (eg, anxiety and depression) and quality of life.[65] Athletes report enhanced quality of life[53] and mental health.[49] These benefits have been proposed to derive from improved social and community interactions[49] and increased physical activity.[20,49] However, not all sport participants experience enhanced psychological health; some have poor quality of life[53] and mental health.[73] The negative impacts of sport participation on psychological health can be due to sustaining injury,[53] competition stress, team selection, and performance pressures.[56] In a systematic review and meta-analysis, athletes who sustained an anterior cruciate ligament injury had impaired quality of life compared to the general population 5 to 20 years after injury.[53] Retired professional cricketers reported a 9% depression prevalence,[73] which is higher than the 3% prevalence in the general population.[135] Baseball participation, culture, and lifestyle may have an impact on psychological health, specifically, the high volume of games played,[45] travel schedules,[133] and drug

[1]Centre for Sport, Exercise and Osteoarthritis Research Versus Arthritis, Oxford, United Kingdom. [2]Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, University of Oxford, Oxford, United Kingdom. [3]Bodleian Health Care Libraries, University of Oxford, Oxford, United Kingdom. This study was funded by the Centre for Sport, Exercise and Osteoarthritis Research Versus Arthritis (grant 21595). The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Garrett S. Bullock, Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, University of Oxford, B4495, Oxford, UK OX3 7LD. E-mail: garrett.bullock@ndorms.ox.ac.uk

and alcohol use.[97] However, there is little understanding of the impact of baseball participation on psychological health across the lifespan.

The purpose of this scoping review was (1) to investigate the relationship between baseball participation and health (musculoskeletal, general, and psychological health) at all ages and competition levels, and (2) to identify research gaps in the existing literature on baseball participation and health.

METHODS

Study Design

To investigate the relationship between baseball participation and health and identify gaps in the literature, we adopted the scoping review process proposed for best practice.[12,92,107] This is a 5-stage process in which the research question is identified, relevant studies are identified, studies are screened and selected from specific inclusion/exclusion criteria, data are charted, and results are collated, summarized, and reported.[12]

Identification of the Research Question

The primary research question (What is the relationship between baseball participation, health, and well-being?) was informed by current knowledge gaps in the baseball literature and by the interests and needs of the baseball community.

Identification of Relevant Studies

To be eligible for inclusion in this review, articles had to meet the following criteria: (1) assess a construct related to musculoskeletal health (eg, injury, pain, physical activity, and injury prevention), general health (eg, physiological function, tobacco and alcohol use, BMI, nutrition, diabetes, and cardiovascular disease), and/or psychological health (eg, mental health, depression, mood, anxiety, quality of life, and fear of reinjury) in current or former baseball participants of any age, sex, or competition level; (2) primary research studies, reviews, meta-analyses, guidelines, or gray literature (including unpublished and ongoing trials, annual reports, dissertations, and conference abstracts); and (3) written in English.

Articles that evaluated the following outcomes and did not report or analyze their relationship to musculoskeletal, general, or psychological health were excluded from the review: (1) baseball performance parameters (eg, pitch velocity, wins and losses, earned run average), (2) biomechanics, (3) bony anatomy unrelated to health outcomes (eg, humeral retrotorsion), (4) player loading parameters (eg, accelerometer data, global positioning systems, session rate of perceived exertion, pitch count, innings count), and (5) joint range of motion or flexibility.

Additional exclusion criteria consisted of (1) studies that only assessed musculoskeletal, general, or psychological health in baseball umpires, baseball spectators/fans, baseball coaches, or baseball card owners/sellers; (2) editorials, columns, or letters to the editor; and (3) cadaveric, in situ, or animal-model studies.

Identification of Key Words and Index Terms

A librarian-assisted computerized search of MEDLINE, CINAHL, Embase, Scopus, PsycINFO, SPORTDiscus, Cochrane Library, EBSCO, Web of Science, and PEDro was conducted. A gray literature search of Google Scholar, www.clinicaltrials.gov, the ISRCTN registry, and ProQuest Dissertations and Theses was conducted. The searches were performed on all titles prior to November 15, 2018. In MEDLINE, Embase, CINAHL, Cochrane Library, PsycINFO, PEDro, www.clinicaltrials.gov, and the ISRCTN registry, only the term used was "baseball*" to increase search inclusivity.[107] All other database searches yielded articles including a term related to "baseball" and a term related to health or well-being (**APPENDIX A**, available at www.jospt.org). The following exclusion terms were applied: "cadavers," "in situ," "in vitro," and "animal studies" (**APPENDIX A**). References were extracted, imported, and tracked in EndNote Version X8 (Clarivate Analytics, Philadelphia, PA).

Study Selection

One independent reviewer (G.S.B.) screened all titles and abstracts for eligibility before retrieving and screening the full texts of all potentially eligible articles to confirm eligibility. A second reviewer (J.U.) completed the same screening process on a random sample of 30% of articles.[107] There was 98% agreement regarding article eligibility between reviewers.

Extracting the Results

Data were extracted by a single reviewer (G.S.B.) and entered in a customized electronic database. Outcome data were stratified into a priori themes of musculoskeletal health, general health, and psychological health.[107] Data extracted included publication year, study type (primary, secondary, or gray literature), country of origin, age group, competition level, study design, study description, surgical procedure (if applicable), analysis design, and key findings.

Collating, Summarizing, and Reporting the Results

Data were collated and summarized for descriptive analysis. Data were explored to identify research gaps concerning the relationship between baseball participation, health, and well-being.[107] Article characteristics were collated to map the overall trends in the data via publication year, country of origin, study design, and theme.

RESULTS

Search Results

A total of 21 359 studies were identified in the initial search. After removing duplicates, 10 574 titles and abstracts were screened, resulting in 926 potentially eligible articles for full-text review (**FIGURE 1**). Of these, 678 articles (**SUPPLEMENTARY DATA FILE**, available at www.jospt.org) met the eligibility criteria and were included in the scoping review.

Year of Publication of Included Studies

There was a substantial incremental increase in published studies over time, with most publications (371, 55%) published between 2010 and 2018 (**FIGURE 2**).

Geographic Location of Included Studies

Of the 678 studies included in this review, 610 (90%) articles were from the United States, 59 (9%) articles were from Japan, 3 (<1%) articles were from Korea, 2 (<1%) articles were from the Netherlands, and fewer than 1% of articles were from Australia, Brazil, Indonesia, or the United Kingdom.

Study Design

Most articles were primary studies (520, 77%), and the most common designs were retrospective (189, 36%) and case studies (161, 31%). There were 87 (13%) secondary studies and 71 (10%) gray literature articles (**FIGURE 3**).

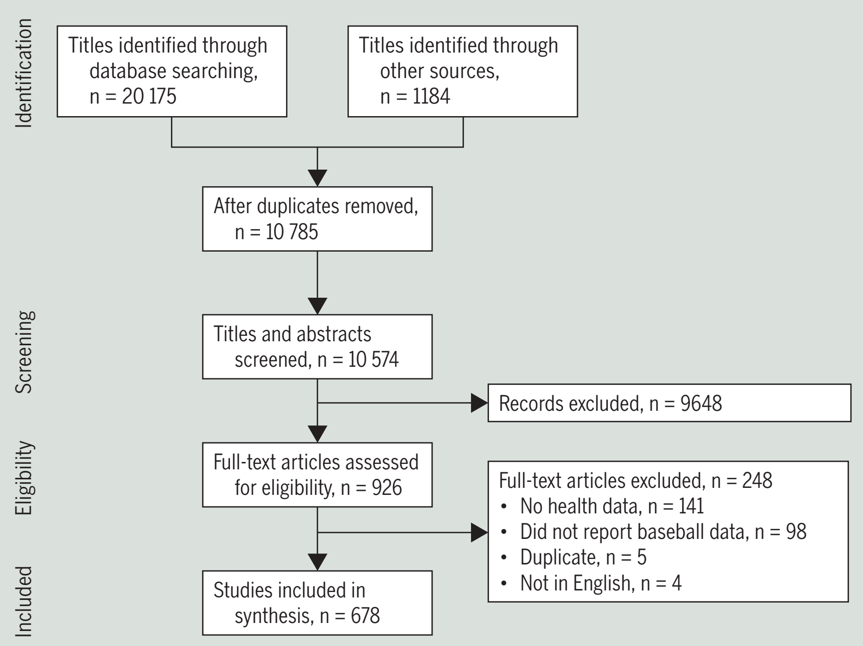

FIGURE 1. Flow diagram demonstrating the scoping review of the literature for the relationship between baseball participation and health.

Participant Characteristics

There were 424 (63%) studies that included only adult (older than 18 years old) baseball players. Adolescents (13-18 years old) were investigated in 132 (19%) studies, and youth (12 years old or younger) baseball players in 122 (18%) studies. Two hundred twenty-nine (34%) studies focused on professional baseball, 77 (11%) studies on collegiate baseball, and 111 (16%) studies on high school baseball. Two studies (less than 1%) investigated female baseball players and 675 (greater than 99%) included only male baseball players. Six hundred fifty-two (96%) studies involved current baseball players and 26 (4%) studies investigated musculoskeletal, general, or psychological health in former baseball players.

Themes

Most articles (583, 86%) investigated musculoskeletal health, 77 (11%) articles investigated general health, and 18 (3%) articles investigated psychological health. **Musculoskeletal Health** Of the 583 articles that investigated musculoskeletal health, 522 (90%) assessed baseball injuries and 61 (10%) assessed surgical outcomes.

Musculoskeletal Health: Injury The most common baseball-related injuries and/or surgery investigated were elbow (218 articles, 37%) and shoulder (197 articles, 34%) injuries (**APPENDIX B**, available at www.jospt.org). Of these articles that investigated only injury, 193 (37%) were epidemiological studies, 153 (29%) were case studies, 66 (13%) were clinical commentaries, 57 (11%) were gray literature, 24 (5%) were studies comparing different physical attributes in injured versus noninjured baseball players, 13 (2%) were systematic reviews, 11 (2%) were injury prevention studies, and 5 (1%) investigated the efficacy of rehabilitation exercises on pain.

Injury incidence ranged from 0.7 to 3.6 injuries per 1000 athlete exposures in professional baseball,[9,23,25,29,31,34,41,114] 4.7 to 5.8 injuries per 1000 athlete exposures in college baseball,[45,76,103,112] and 0.8 to 4.0 injuries per 1000 athlete exposures in high school baseball.[18,32,76,80,115,116,122,126] Two studies observed increased injury prevalence from 2005 to 2015 and from 1998 to 2015 at the high school[116] and professional levels, respectively.[34]

Professional baseball player upper extremity injury incidence accounted for 51% of all injuries,[114] with 21% involving the shoulder[34] and 10% involving the elbow.[29] College baseball player upper extremity injury incidence accounted for 52% to 58% of all injuries,[103,112] with 0.37 and 0.18 injuries per 1000 athlete exposures for the shoulder and elbow.[45,103] High school baseball player upper extremity injury incidence accounted for 63% of all injuries,[127] 1.39 to 1.90 shoulder injuries per 1000 athlete exposures,[18,80,122] and 0.86 to 0.92 elbow injuries per 1000 athlete exposures.[116,122]

Professional baseball player lower extremity injury incidences were 0.7 and 1.2 per 1000 athlete exposures for the hamstring[9] and knee.[41] Lower extremity injury accounted for 27% of all injuries in college baseball players,[103] and 22% of all injuries in high school baseball players.[127]

Injury prevention articles consisted of 5 gray literature,[64,72,82,105,139] 1 clinical commentary,[101] and 5 primary studies.[83,121,124,129,157] Injury reduction ranged from 25% to 57% in the injury prevention groups compared to controls.[83,121,124,129,157] Two studies[124,157] investigated hamstring injury prevention programs in individual professional organizations, and observed a 40% reduction in hamstring injury incidence[157] and a reduction of 50% in days missed.[124] Three studies[83,121,129] investigated the efficacy of injury prevention strategies in high school baseball players, with injury incidence decreasing from a range of 27% to 57% in the prevention groups.[121,129] Using wood or metal bats did not change injury incidence.[83]

No studies investigated the relationship between sustaining an injury while playing baseball as a youth, adolescent, or collegiate athlete and the long-term health effects across the lifespan. One study investigated the long-term musculoskeletal consequences of playing baseball as an adult, with 19% of retired baseball players in Australia having osteoarthritis and 24% having restricted mobility.[104]

Musculoskeletal Health: Surgical Outcomes Fifty-five (90%) surgical outcome studies were primary studies and 6 (10%) were secondary studies. Forty-one (67%) studies evaluated ulnar collateral ligament reconstruction (UCLR) outcomes. The 3 studies that reported UCLR incidence or prevalence[24,35,119] found that 10% of all professional baseball players and 16% of professional pitchers had undergone UCLR,[35] annual UCLR incidence in professional baseball substantially rose from 1974 to 2015,[24] and 2.5% of college players underwent UCLR (0.86 UCLRs per team).[119] Five studies investigated UCLR revision surgery,[46,50,75,95,153] although only 1 study reported revision rate.[95] Time to return to play and total number of pitches were not associated with an increased risk of revision in professional baseball players.[50,75] No studies investigated UCLR revision outcomes in high school or collegiate baseball players.

Three studies investigated rotator cuff surgery outcomes.[100,108,156] Three studies investigated superior labrum anterior-to-posterior lesion surgical outcomes.[28,36,57] Other surgical studies investigated osteochondritis dissecans, latissimus dorsi, hamate, and anterior cruciate ligament surgeries (each investigated in 2 studies). Bennett lesion surgery, bicep repair, and femoral acetabular impingement, hip, and olecranon surgeries were each investigated in 1 study. No studies investigated revision outcomes of these surgical procedures.

General Health Forty-three (56%) studies that investigated general health in

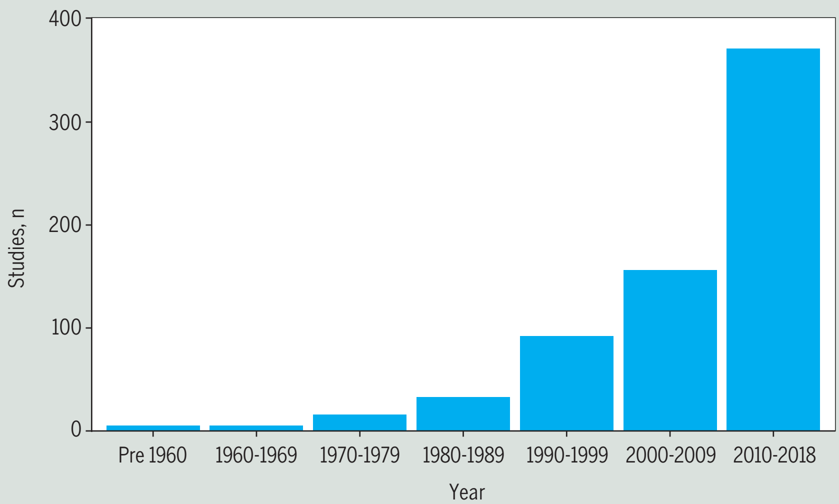

FIGURE 2. Year of publication reported by decade.

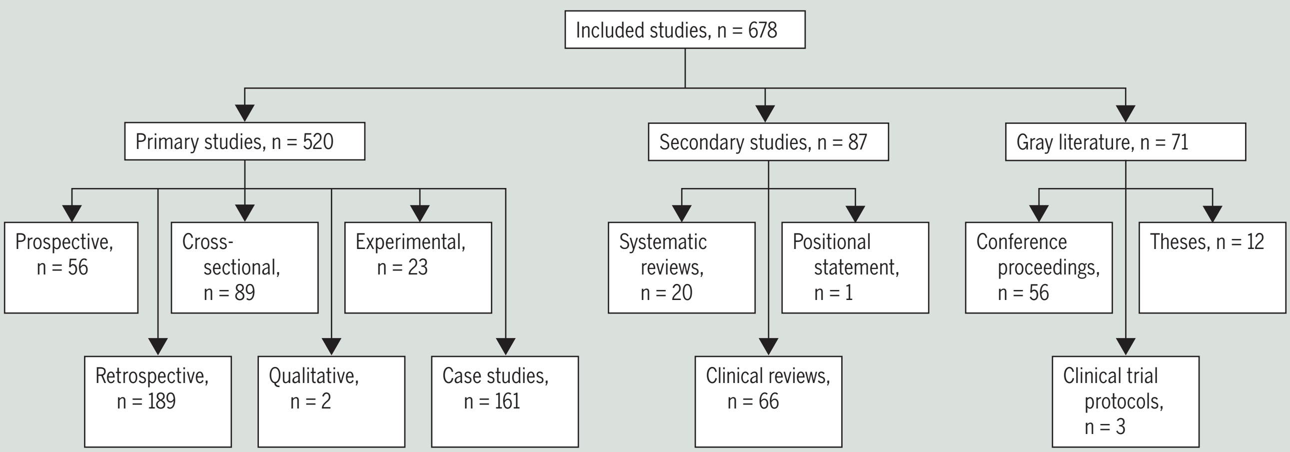

FIGURE 3. Study design for included literature.

baseball participants assessed tobacco use, 16 (21%) studies investigated longevity, 5 (6%) studies investigated alcohol use, 5 (6%) studies investigated drug use, and 8 (10%) studies investigated markers of physiological health (BMI, body fat, cholesterol, diabetes, tuberculosis, and cardiovascular health).

General Health: Tobacco Smokeless tobacco, or spit tobacco, was the most commonly used tobacco product, with prevalence ranging from 31% to 50% of professional baseball players.[38,142] High school, college, and professional baseball players all had an increased prevalence of smokeless tobacco use compared to the general population.[38,143,146] Tobacco use was reduced following the implementation of organizational policy changes and tobacco cessation programs.[125,147]

General Health: Alcohol High school baseball players were found to have a 50% increase in alcohol use compared to high school nonathletes,[43] and to consume similar amounts of alcohol compared to high school American football players.[43] In 2 small studies, career professional baseball player alcohol consumption increased from 38% to 69% from rookie year to retirement.[97,155] One study discussed the negative health implications of alcohol in the professional baseball clubhouse.[17]

General Health: Drugs Three (60%) studies investigated drugs including opioids, marijuana, and amphetamines,[19,43,70] and 2 (40%) studies investigated anabolic steroid use in current professional baseball players.[132,140] High school baseball players were more likely to use marijuana compared to high school nonathletes.[43] There were 4 reported opioid overdose deaths in former professional baseball players over the last century,[19] and 1 study described media coverage of baseball drug use and its implications for future baseball players.[44]

Amphetamine use was highly prevalent prior to the ban by Major League Baseball. Use has greatly decreased.[70] No studies investigated drug use in current or former collegiate baseball players. Two studies reported on the overall bodily effects and cultural impact of steroid use in professional baseball players.[132,140] Specifically, future health risks due to steroid use included increased risk of heart disease, cancer, and decreased mental health.[140] Baseball steroid use was allowed to become pervasive due to the established culture that valued winning above fair play or future health.[132] No studies investigated the prevalence of steroid use in baseball.

General Health: Longevity All 16 studies that investigated longevity included former professional baseball players. Six studies investigated factors affecting professional baseball player longevity. Birth date and handedness did not affect longevity.[2,5] Earlier professional debut and being a Hall of Fame player negatively affected longevity.[3,6,16] Increased overall professional career length positively affected longevity.[1] Professional baseball players had longer life expectancies compared to US averages.[1,3,4,120]

General Health: Physiological Health In current professional baseball players, 2 studies investigated cholesterol levels,[26,27] 2 studies investigated body fat percentage,[30,58] 1 study investigated BMI,[33] 2 case studies investigated either diabetes[60] or tuberculosis[106] management in a single player, and 1 study investigated cardiovascular risk.[67] Twenty-eight percent of professional baseball players had cholesterol levels over 200 mg/dL, and 12% had triglycerides over 150 mg/dL.[26,27] Professional baseball players had similar body fat percentage to professional basketball and mixed martial arts athletes.[58] One study found that professional baseball players had increased BMI compared to the general US population, and that BMI had increased in professional baseball players over the last century.[33] Current professional baseball players had a 10% lower cardiovascular risk compared to current professional football players.[67]

Psychological Health Fifteen (83%) articles investigated mental health and 3 (17%) investigated quality of life.

Psychological Health: Mental Health Five studies investigated suicide risk factors and incidence in former professional baseball players. Prior to 1988, suicide rates of 0.84[150] and 1%[89] were reported in professional baseball players, which were lower than the general population rate of 1.9%.[150] One study found that professional baseball participation was protective against suicide,[150] and another study was inconclusive.[89] Birth month and baseball performance were not risk factors for suicide in professional baseball players.[88,91,131] Of the 5 studies that investigated anxiety, only 1 small study evaluated anxiety prevalence and found that 9 of 22 college baseball players reported anxiety scores 1 SD above the population normative mean.[134] Three case studies investigated precompetitive anxiety,[66,71,81] and 1 study investigated the relationship between anxiety and recovery, finding that utilizing relaxation strategies decreased anxiety and improved recovery in collegiate baseball players.[141] Two studies investigated stress in youth athletes and found no association between baseball participation and stress levels.[11,14]

Psychological Health: Quality of Life and Life Satisfaction Quality of life or life satisfaction was investigated in 3 studies.[84,87,138] One study used the Medical Outcomes Study 36-Item Short-Form Health Survey, and observed that high school baseball players with shoulder pain had impaired physical components of quality of life compared to high school baseball players without shoulder pain.[84] One study, using the World Health Organization-Quality of Life questionnaire, observed that youth baseball players involved in the national Brazilian baseball and softball training center had decreased social relations and overall World Health Organization-Quality of Life questionnaire scores compared to youth baseball players not involved in a training center.[138] The third study found that 51% of retired professional baseball players reported moderate life satisfaction and 15% reported low life satisfaction, although there was no comparison group in this study.[87]

DISCUSSION

The majority of studies in our scoping review were primary research. Most methodological designs were retrospective (36%) or case studies (31%), demonstrating a potential for high risk of bias. Ninety percent of studies investigated US baseball participants, which does not reflect worldwide participation. Baseball injury incidence ranged from 0.7 to 5.8 injuries per 1000 athlete exposures. Upper extremity injuries accounted for 51% to 63% and lower extremity injuries accounted for 22% to 27% of all baseball injuries. Baseball players from all competition levels reported increased tobacco (31%-50% of baseball players regularly used tobacco), alcohol, and drug use compared to the general population. Professional baseball players had increased longevity compared to the general population and a 10% decrease in cardiovascular risk compared to American football players. There was a paucity of literature investigating the relationship between playing baseball and psychological health.

Baseball and Geographic Location

Baseball is played throughout the world,[13] and over 40% of professional baseball players reside outside the United States.[78] However, 90% of studies were based in the United States. Baseball players from different countries have different levels of physical performance.[13,21] Youth baseball players of a similar age and playing standard from Latin America and Asia could throw farther and faster compared to US baseball players.[13] Due to worldwide participation,[13,78] and potentially different physical and cultural training and playing norms,[78] there is a need to investigate the relationship between baseball player musculoskeletal, general, and psychological health in different geographic locations.

Baseball and Musculoskeletal Health

The majority of studies in this review investigated injury or surgery in baseball participants. Baseball injuries have increased in the past 20 years, at all competition levels.[34,116] This is similar to other sports, such as soccer and football.[8,152] The long-term physical implications of baseball injuries have only been investigated in 1 Australian study, which found that as many as 1 in 5 retired baseball players suffered from osteoarthritis and 1 in 4 suffered from reduced mobility.[104] Former athletes in other sports appear to have an increased risk of osteoarthritis and joint pain, which may be due to past injury or overall playing volume.[42,73] There has been a continued increase in baseball-related surgical procedures in the last 50 years.[24,68] Surgery is a substantial health care burden and does not guarantee return to full function.[68,113] With the rise in baseball injuries and surgeries,[34,68] there is a need to implement consistent, organization-wide injury prevention strategies and understand the long-term implications of injury at all baseball competition levels.

Baseball and Tobacco Use

The use of smokeless tobacco in baseball players at all competition levels is more frequent than that in the general population. This is a concern, considering tobacco use is associated with an increased risk of cancer[149] and is related to a high risk of alcohol and drug use.[37] Within the general US population, smokeless tobacco use has decreased in the last decade. However, use has increased in athletes in all major North American sports by almost 2%.[7] Tobacco use has a historical relationship to baseball, is heavily integrated into baseball culture, and dates back to the 19th century.[47] Importantly, our findings suggest that tobacco use at all baseball competition levels continues to be high[130,144,146] but can be decreased through targeted interventions.[130,145,147] A continued focus on implementing organization- and team-based tobacco cessation programs would mitigate tobacco use in baseball.

Baseball and Alcohol and Drug Use

Alcohol use and drug use are associated with an increased risk of morbidity,[77] cancer,[22] and death.[54,136] Alcohol and recreational drugs were used more frequently in baseball players at the high school and professional levels than in the general population, but no more frequently than football, basketball, or soccer athletes.[43] Alcohol use and drug use are high among all collegiate athletes,[62] and have remained steady over time.[10] Increased consumption of drugs and alcohol in athletes has been associated with risky behavior and higher sexual violence rates compared to nonathletes.[55,109] Alcohol and drug cessation programs have been initiated in collegiate and professional sports with success.[102] These findings highlight the need for continued monitoring of alcohol and drug use and implementation of cessation strategies for athletes at all levels.

There were no studies that investigated the prevalence of steroid use in baseball players. However, 2 studies reported the overall bodily effects and cultural impact of steroid use in professional baseball players.[132,140] Since the instigation of Major League Baseball performance-enhancing drug (PED) testing in 2003, professional baseball has internally tabulated PED use.[63] However, there are no similar investigations into steroid and PED use in college or high school players. The pressures related to PED use[63] and the lack of literature investigating steroid use demonstrate the need to examine the use of such substances in baseball players at all levels.

Baseball and Longevity

Professional baseball players have greater life expectancy than the general US population. Sports participation, which involves physical activity,[148] can play an important role in increasing longevity.[96] However, the United States has seen a rise in sedentary behavior across the lifespan.[99] A sedentary lifestyle has many negative health impacts, including type 2 diabetes,[86] cardiovascular disease,[86] and increased mortality.[94] Similar results regarding increased longevity have been observed in professional football, basketball, and cycling athletes.[85] The increased life expectancy may be due to increased physical activity levels throughout the lifespan,[85] although this has not been explored within baseball. While there is evidence for increased longevity in professional athletes from a myriad of sports,[85] there is currently no evidence on baseball participation and longevity at nonprofessional levels.

Baseball and Physiological Health

Increased BMI is a risk factor for multiple diseases, including diabetes,[61] osteoarthritis,[117] cardiovascular disease,[15] and stroke.[52] The study that investigated BMI in professional baseball players found that their BMI was greater than that of the general population.[33] Overall athlete body mass has increased considerably over the last century, due to athlete body-type selection and increased training.[110] Increased BMI has been associated with greater cardiovascular disease risk in current or retired athletes in football.[67] However, current baseball players did not have increased cardiovascular disease risk.[67] More than one quarter of professional baseball players had high cholesterol levels.[26,27] In comparison, 39% of American men in the general population are deemed "at risk" due to cholesterol levels.[40] The scarce research investigating baseball player BMI and cholesterol and cardiovascular risk[26,27,33,67] highlights a need for further information regarding the long-term health impacts of baseball participation.

Baseball and Psychological Health

Few studies investigated psychological health in current or former baseball participants at any competition level. Studies that investigated psychological health focused on professional baseball players. Two of 16 studies studied youth athletes. Reported suicide rates in baseball players prior to 1988 were approximately half the US average of 1.9%.[89,150] Since 1988, there have been numerable changes in baseball, such as the steroid era, that may affect suicide rates.[132] Professional athlete suicides have been attributed to steroid use, increased stress, or an inability to transition to life after sport.[90] These factors can all have potential effects on mental health.[90,132]

Other former professional athletes have high rates of mental disorders such as anxiety, depression, and sleep disturbance.[59,123] Former professional cricket and soccer players have depression rates ranging from 37% to 39%,[59,123] which are higher than the UK national rate of 3.4%.[135] Three studies investigated the prevalence or association of other mental health factors such as anxiety and stress in baseball,[11,14,134] and no studies investigated depression.

No studies compared quality of life or life satisfaction between current or former baseball players and nonbaseball players. In retired professional baseball players, 51% reported moderate life satisfaction and 15% reported low life satisfaction.[87] In comparison, 5.6% of the general US population reported low or very low life satisfaction.[137] This suggests that retired baseball players may report lower life satisfaction compared to that of the general population, highlighting the importance of further research investigating psychological health in current and former baseball players.

Further Research Priorities

A summary of the key knowledge gaps in relation to baseball, health, and well-being is presented in the **TABLE**.

Strengths and Limitations

This is the first study to review the existing literature on the relationship between baseball participation, health, and well-being. This study was exhaustive and incorporated articles from multiple published and unpublished sources, enabling a comprehensive collation and summary of the literature. This scoping review only incorporated studies that were written in English, which may have biased the results. The majority of baseball research has focused on professional American players, which is disproportionate to baseball geographic distribution. Thus, there may be limited generalizability of the results to baseball players of all participation levels and throughout the world.

CONCLUSION

Baseball injury incidence ranged from 0.7 to 3.6 injuries per 1000 athlete exposures in professional baseball, 4.7 to 5.8 injuries per 1000 athlete exposures in college baseball, and

TABLE Research Gaps in the Literature Regarding the Relationship Between Baseball, Health, and Well-being

Research Gap Relating to Baseball	Explanation
Long-term musculoskeletal, general, and psychological health implications of baseball participation	Very few studies investigated the long-term effect of playing baseball on musculoskeletal, general, and psychological health at any competition level
Youth and high school	Most research in youth and high school populations has studied musculoskeletal injury. Further research is needed to investigate how baseball participation affects general and psychological health in youth and high school athletes
Current state of the musculoskeletal, general, and psychological health of collegiate baseball players	Only 11% of studies focused on collegiate baseball players. The majority of these were case studies. Further research is needed to evaluate musculoskeletal, general, and psychological health in collegiate baseball players
The relationship between psychological health and baseball participation at all competition levels	No studies compared quality of life, life satisfaction, anxiety, or depression between current or former baseball players and the general population at any competition level
Injury prevention studies	Many studies investigated musculoskeletal injury risk and prevalence. However, there are few prospective or randomized controlled trial injury prevention studies

0.8 to 4.0 injuries per 1000 athlete exposures in high school baseball. Professional baseball players have an increased life expectancy compared to the general population. Baseball players have high tobacco use, and high alcohol and other drug use, compared to the general population. Gaps in the literature in need of further prospective, longitudinal research include psychological health in current and former baseball players from all standards of play and long-term health outcomes of baseball participation. ◉

KEY POINTS

FINDINGS: Injury incidence ranged from 0.7 to 3.6 injuries per 1000 athlete exposures in professional baseball, 4.7 to 5.8 injuries per 1000 athlete exposures in college baseball, and 0.8 to 4.0 injuries per 1000 athlete exposures in high school baseball. Baseball players have high tobacco use (prevalence ranging from 31% to 50%), and increased alcohol and drug use, compared to the general population.

IMPLICATIONS: The high and increasing prevalence of injury in baseball highlights the need for effective injury prevention strategies. The high efficacy of tobacco and alcohol cessation programs demonstrates the need for increased implementation of these programs in baseball. There is limited literature to guide clinicians and current and former baseball participants at all competition levels concerning psychological health.

CAUTION: Most baseball research has focused on professional American players, which is disproportionate to global baseball participation levels. Our results may not generalize to baseball players of all participation levels and throughout the world.

STUDY DETAILS

DATA SHARING: All data relevant to the study are included in the article or are available as a supplementary file.

AUTHOR CONTRIBUTIONS: All authors were involved in planning, methodology design, and editing the manuscript. Drs Bullock and Filbay wrote the first draft of the manuscript and tabulated and synthesized the data.

ATHLETE AND PUBLIC INVOLVEMENT: Four former professional baseball players, a former professional baseball strength coach, 4 collegiate baseball coaches, and 3 baseball physical therapists and athletic trainers were consulted throughout this study and during manuscript development regarding study design, thematic synthesis, and manuscript wording.

REFERENCES

1. Abel EL, Kruger ML. The healthy worker effect in Major League Baseball revisited. *Res Sports Med*. 2006;14:83-87. https://doi.org/10.1080/15438620500528406
2. Abel EL, Kruger ML. Left-handed Major-League Baseball players and longevity re-examined. *Percept Mot Skills*. 2004;99:990-992. https://doi.org/10.2466/pms.99.3.990-992
3. Abel EL, Kruger ML. The longevity of Baseball Hall of Famers compared to other players. *Death Stud*. 2005;29:959-963. https://doi.org/10.1080/07481180500299493
4. Abel EL, Kruger ML. Longevity of Major League Baseball players. *Res Sports Med*. 2005;13:1-5. https://doi.org/10.1080/15438620590922031
5. Abel EL, Kruger ML. Mortality salience of birthdays on day of death in the Major Leagues. *Death Stud*. 2009;33:175-184. https://doi.org/10.1080/07481180802138936
6. Abel EL, Kruger ML. Precocity predicts shorter life for Major League Baseball players: confirmation of McCann's precocity-longevity hypothesis. *Death Stud*. 2007;31:933-940. https://doi.org/10.1080/07481180701603428
7. Agaku IT, Singh T, Jones SE, et al. Combustible and smokeless tobacco use among high school athletes—United States, 2001-2013. *MMWR Morb Mortal Wkly Rep*. 2015;64:935-939. https://doi.org/10.15585/mmwr.mm6434a2
8. Agel J, Rockwood T, Klossner D. Collegiate ACL injury rates across 15 sports: National Collegiate Athletic Association Injury Surveillance System data update (2004-2005 through 2012-2013). *Clin J Sport Med*. 2016;26:518-523. https://doi.org/10.1097/JSM.0000000000000290
9. Ahmad CS, Dick RW, Snell E, et al. Major and Minor League Baseball hamstring injuries: epidemiologic findings from the Major League Baseball Injury Surveillance System. *Am J Sports Med*. 2014;42:1464-1470. https://doi.org/10.1177/0363546514529083
10. Anderson WA, Albrecht RR, McKeag DB, Hough DO, McGrew CA. A national survey of alcohol and drug use by college athletes. *Phys Sportsmed*. 1991;19:91-104. https://doi.org/10.1080/00913847.1991.11702148
11. Arimond G, Petrick JF. Organized baseball's effect on eight-year-old boys' perceived locus of control. *J Appl Recreat Res*. 1998;23:203-223.
12. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol*. 2005;8:19-32. https://doi.org/10.1080/1364557032000119616
13. Axe MJ, Strube M, Osinski D, Andrews JR, Snyder-Mackler L. A speed distance-based classification system for injury prevention and research in international and domestic youth baseball players. *Int J Sports Phys Ther*. 2014;9:346-355.
14. Bass M. *Coping with competitive sports stressors: an exploratory study of gender differences among 4-10-year-olds in baseball and softball* [dissertation]. New Castle, DE: Wilmington University; 2015.
15. Bastien M, Poirier P, Lemieux I, Després JP. Overview of epidemiology and contribution of obesity to cardiovascular disease. *Prog Cardiovasc Dis*. 2014;56:369-381. https://doi.org/10.1016/j.pcad.2013.10.016
16. Becker DJ, Chay KY, Swaminathan S. Mortality and the Baseball Hall of Fame: an investigation into the role of status in life expectancy [abstract]. International Health Economics Association 6th World Congress: Explorations in Health Economics; July 8-11, 2007; Copenhagen, Denmark.
17. Berneman SB. One strike and you're out: alcohol in the Major League Baseball clubhouse. *Vanderbilt J Entertain Technol Law*. 2009;11:399-424.
18. Bonza JE, Fields SK, Yard EE, Comstock RD. Shoulder injuries among United States high school athletes during the 2005–2006 and 2006–2007 school years. *J Athl Train*. 2009;44:76-83. https://doi.org/10.4085/1062-6050-44.1.76
19. Boren S, Erickson TB. Toxicological deaths of Major League Baseball players. *J Toxicol Clin Toxicol*. 1998;36:737-742. https://doi.org/10.3109/15563659809162625
20. Brunet J, Sabiston CM, Chaiton M, et al. The association between past and current physical activity and depressive symptoms in young adults: a 10-year prospective study. *Ann Epidemiol*. 2013;23:25-30. https://doi.org/10.1016/j.annepidem.2012.10.006
21. Bullock GS, Chapman T, Joyce T, Prengle R, Stern T, Butler RJ. Examining differences in movement competency in professional baseball players born in the United States and Dominican Republic. *J Sport Rehabil*. 2018;27:397-402. https://doi.org/10.1123/jsr.2016-0251
22. Cai S, Li Y, Ding Y, Chen K, Jin M. Alcohol drinking and the risk of colorectal cancer death: a meta-analysis. *Eur J Cancer Prev*. 2014;23:532-539. https://doi.org/10.1097/CEJ.0000000000000076
23. Camp CL, Conte S, Cohen SB, et al. Epidemiology and impact of abdominal oblique

injuries in Major and Minor League Baseball. *Orthop J Sports Med*. 2017;5:2325967117694025. https://doi.org/10.1177/2325967117694025

24. Camp CL, Conte S, D'Angelo J, Fealy S. Epidemiology of ulnar collateral ligament reconstruction in Major and Minor League Baseball pitchers: comprehensive report on 1,313 cases [abstract]. *Orthop J Sports Med*. 2017;5:2325967117S2325900369. https://doi.org/10.1177/2325967117S00369

25. Camp CL, Curriero FC, Pollack KM, et al. The epidemiology and effect of sliding injuries in Major and Minor League Baseball players. *Am J Sports Med*. 2017;45:2372-2378. https://doi.org/10.1177/0363546517704835

26. Cantwell JD. High-sensitivity C-reactive protein levels in players on a Major League Baseball team. *Am J Cardiol*. 2003;92:467-468. https://doi.org/10.1016/s0002-9149(03)00670-2

27. Cantwell JD. Serum lipid levels in a Major League Baseball team. *Am J Cardiol*. 2002;90:1395-1397. https://doi.org/10.1016/s0002-9149(02)02882-5

28. Ciccotti MG, Neuman B, Boisvert CB, Reiter B, Lawson K, Cohen SB. Results of arthroscopic repair of type II SLAP repairs in overhead athletes: assessment of return to pre-injury playing level and satisfaction [abstract]. *Arthroscopy*. 2011;27:e201. https://doi.org/10.1016/j.arthro.2011.08.196

29. Ciccotti MG, Pollack KM, Ciccotti MC, et al. Elbow injuries in professional baseball: epidemiological findings from the Major League Baseball Injury Surveillance System. *Am J Sports Med*. 2017;45:2319-2328. https://doi.org/10.1177/0363546517706964

30. Coleman AE. Skinfold estimates of body fat in Major League Baseball players. *Phys Sportsmed*. 1981;9:77-82. https://doi.org/10.1080/00913847.1981.11711186

31. Coleman SH, Mayer SW, Tyson JJ, Pollack KM, Curriero FC. The epidemiology of hip and groin injuries in professional baseball players. *Am J Orthop (Belle Mead NJ)*. 2016;45:168-175.

32. Collins CL, Comstock RD. Epidemiological features of high school baseball injuries in the United States, 2005–2007. *Pediatrics*. 2008;121:1181-1187. https://doi.org/10.1542/peds.2007-2572

33. Conroy DE, Wolin KY, Carnethon MR. Overweight and obesity among Major League Baseball players: 1871–2015 [letter]. *Obes Res Clin Pract*. 2016;10:610-612. https://doi.org/10.1016/j.orcp.2016.09.003

34. Conte S, Camp CL, Dines JS. Injury trends in Major League Baseball over 18 seasons: 1998-2015. *Am J Orthop (Belle Mead NJ)*. 2016;45:116-123.

35. Conte SA, Fleisig GS, Dines JS, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. *Am J Sports Med*. 2015;43:1764-1769. https://doi.org/10.1177/0363546515580792

36. Conway JE. Arthroscopic repair of partial-thickness rotator cuff tears and SLAP lesions in professional baseball players. *Orthop Clin North Am*. 2001;32:443-456. https://doi.org/10.1016/s0030-5898(05)70213-3

37. Conway KP, Green VR, Kasza KA, et al. Co-occurrence of tobacco product use, substance use, and mental health problems among adults: findings from Wave 1 (2013–2014) of the Population Assessment of Tobacco and Health (PATH) Study. *Drug Alcohol Depend*. 2017;177:104-111. https://doi.org/10.1016/j.drugalcdep.2017.03.032

38. Cooper J, Ellison JA, Walsh MM. Spit (smokeless)-tobacco use by baseball players entering the professional ranks. *J Athl Train*. 2003;38:126-132.

39. Crotin RL. A collaborative approach to prevent medial elbow injuries in baseball pitchers. *Strength Cond J*. 2011;33:1-24. https://doi.org/10.1519/SSC.0b013e318227cb56

40. D'Agostino RB, Sr., Vasan RS, Pencina MJ, et al. General cardiovascular risk profile for use in primary care: the Framingham Heart Study. *Circulation*. 2008;117:743-753. https://doi.org/10.1161/CIRCULATIONAHA.107.699579

41. Dahm DL, Curriero FC, Camp CL, et al. Epidemiology and impact of knee injuries in Major and Minor League Baseball players. *Am J Orthop (Belle Mead NJ)*. 2016;45:E54-E62.

42. Davies MAM, Judge AD, Delmestri A, et al. Health amongst former rugby union players: a cross-sectional study of morbidity and health-related quality of life. *Sci Rep*. 2017;7:11786. https://doi.org/10.1038/s41598-017-12130-y

43. Denham BE. Alcohol and marijuana use among American high school seniors: empirical associations with competitive sports participation. *Sociol Sport J*. 2011;28:362-379. https://doi.org/10.1123/ssj.28.3.362

44. Denham BE. Drug use in baseball. In: Møller V, Waddington I, Hoberman JM, eds. *Routledge Handbook of Drugs and Sport*. New York, NY: Taylor & Francis/Routledge; 2015:ch 7.

45. Dick R, Sauers EL, Agel J, et al. Descriptive epidemiology of collegiate men's baseball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *J Athl Train*. 2007;42:183-193.

46. Dines JS, Yocum LA, Frank JB, El Attrache NS, Gambardella RA, Jobe FW. Revision surgery for failed elbow medial collateral ligament reconstruction. *Am J Sports Med*. 2008;36:1061-1065. https://doi.org/10.1177/0363546508314796

47. Eaves T. The relationship between spit tobacco and baseball. *J Sport Soc Issues*. 2011;35:437-442. https://doi.org/10.1177/0193723511429826

48. Ebben WP, Hintz MJ, Simenz CJ. Strength and conditioning practices of Major League Baseball strength and conditioning coaches. *J Strength Cond Res*. 2005;19:538-546.

49. Eime RM, Young JA, Harvey JT, Charity MJ, Payne WR. A systematic review of the psychological and social benefits of participation in sport for children and adolescents: informing development of a conceptual model of health through sport. *Int J Behav Nutr Phys Act*. 2013;10:98. https://doi.org/10.1186/1479-5868-10-98

50. Erickson BJ, Chalmers PN, Bach BR, Jr., et al. Length of time between surgery and return to sport after ulnar collateral ligament reconstruction in Major League Baseball pitchers does not predict need for revision surgery. *J Shoulder Elbow Surg*. 2017;26:699-703. https://doi.org/10.1016/j.jse.2017.01.014

51. Feeley BT, Schisel J, Agel J. Pitch counts in youth baseball and softball: a historical review. *Clin J Sport Med*. 2018;28:401-405. https://doi.org/10.1097/JSM.0000000000000446

52. Feigin VL, Roth GA, Naghavi M, et al. Global burden of stroke and risk factors in 188 countries, during 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet Neurol*. 2016;15:913-924. https://doi.org/10.1016/S1474-4422(16)30073-4

53. Filbay SR, Culvenor AG, Ackerman IN, Russell TG, Crossley KM. Quality of life in anterior cruciate ligament-deficient individuals: a systematic review and meta-analysis. *Br J Sports Med*. 2015;49:1033-1041. https://doi.org/10.1136/bjsports-2015-094864

54. Fischbach P. The role of illicit drug use in sudden death in the young. *Cardiol Young*. 2017;27:S75-S79. https://doi.org/10.1017/S1047951116002274

55. Frintner MP, Rubinson L. Acquaintance rape: the influence of alcohol, fraternity membership, and sports team membership. *J Sex Educ Ther*. 1993;19:272-284. https://doi.org/10.1080/01614576.1993.11074089

56. Gastin PB, Meyer D, Robinson D. Perceptions of wellness to monitor adaptive responses to training and competition in elite Australian football. *J Strength Cond Res*. 2013;27:2518-2526. https://doi.org/10.1519/JSC.0b013e31827fd600

57. Gilliam BD, Douglas L, Fleisig GS, et al. Return to play and outcomes in baseball players after superior labral anterior-posterior repairs. *Am J Sports Med*. 2018;46:109-115. https://doi.org/10.1177/0363546517728256

58. Gochioco M, Brown L, Coburn J, et al. A comparison of the physiological profiles of mixed martial artists and football, basketball, and baseball players [abstract]. *J Strength Cond Res*. 2011;25:S55-S56. https://doi.org/10.1097/01.JSC.0000395665.90152.20

59. Gouttebarge V, Frings-Dresen MH, Sluiter JK. Mental and psychosocial health among current and former professional footballers. *Occup Med (Lond)*. 2015;65:190-196. https://doi.org/10.1093/occmed/kqu202

60. Gravlee JR, Barrett JJ. Transient global amnesia in a collegiate baseball player with type I diabetes mellitus: a case report. *J Athl Train*. 2011;46:319-321. https://doi.org/10.4085/1062-6050-46.3.319

61. Gray N, Picone G, Sloan F, Yashkin A. Relation between BMI and diabetes mellitus and its complications among US older adults. *South Med J*. 2015;108:29-36. https://doi.org/10.14423/SMJ.0000000000000214

62. Green GA, Uryasz FD, Petr TA, Bray CD. NCAA study of substance use and abuse habits of college student-athletes. *Clin J Sport Med*. 2001;11:51-56. https://doi.org/10.1097/00042752-200101000-00009
63. Grossman M, Kimsey T, Moreen J, Owings M. Steroids and Major League Baseball. Available at: https://faculty.haas.berkeley.edu/rjmorgan/mba211/Steroids%20and%20Major%20League%20Baseball.pdf. Accessed December 17, 2019.
64. Grove DS. *Examining the relationship between throwing injuries sustained in adolescent baseball players and use of an injury prevention smartphone application "Throw Like a Pro"* [thesis]. Missoula, MT: University of Montana; 2016.
65. Hall LH, Johnson J, Watt I, Tsipa A, O'Connor DB. Healthcare staff wellbeing, burnout, and patient safety: a systematic review. *PLoS One*. 2016;11:e0159015. https://doi.org/10.1371/journal.pone.0159015
66. Han DH, Kim BN, Cheong JH, Kang KD, Renshaw PF. Anxiety and attention shifting in professional baseball players. *Int J Sports Med*. 2014;35:708-713. https://doi.org/10.1055/s-0033-1363235
67. Helzberg JH, Waeckerle JF, Camilo J, et al. Comparison of cardiovascular and metabolic risk factors in professional baseball players versus professional football players. *Am J Cardiol*. 2010;106:664-667. https://doi.org/10.1016/j.amjcard.2010.04.022
68. Hodgins JL, Vitale M, Arons RR, Ahmad CS. Epidemiology of medial ulnar collateral ligament reconstruction: a 10-year study in New York State. *Am J Sports Med*. 2016;44:729-734. https://doi.org/10.1177/0363546515622407
69. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42:311-319.
70. Howard J. "Corzine, Michael. *Team Chemistry: The History of Drugs and Alcohol in Major League Baseball*" [review]. *J Sport Hist*. 2017;44:104-106. https://doi.org/10.5406/jsporthistory.44.1.0104
71. Hubbard JT. *Intensity and interpretation of pre-competitive anxiety in high school baseball players* [thesis]. Fullerton, CA: California State University, Fullerton; 2006.
72. Jones KT. *Shoulder strength and conditioning for injury prevention in baseball players* [dissertation]. Ft Myers, FL: Florida Gulf Coast University; 2014.
73. Jones ME, Davies MAM, Leyland KM, et al. Osteoarthritis and other long-term health conditions in former elite cricketers. *J Sci Med Sport*. 2018;21:558-563. https://doi.org/10.1016/j.jsams.2017.10.013
74. Kahn JP. Baseball, alcohol and public health. *Am J Bioeth*. 2007;7:3. https://doi.org/10.1080/15265160701511487
75. Keller RA, Mehran N, Marshall NE, et al. Major League pitching workload after primary ulnar collateral ligament reconstruction and risk for revision surgery. *J Shoulder Elbow Surg*. 2017;26:288-294. https://doi.org/10.1016/j.jse.2016.11.008
76. Kerr ZY, Roos KG, Djoko A, Dompier TP, Marshall SW. Rankings of high school sports injury rates differ based on time loss assessments. *Clin J Sport Med*. 2017;27:548-551. https://doi.org/10.1097/JSM.0000000000000405
77. Kim SK, Hong SH, Chung JH, Cho KB. Association between alcohol consumption and metabolic syndrome in a community-based cohort of Korean adults. *Med Sci Monit*. 2017;23:2104-2110. https://doi.org/10.12659/msm.901309
78. Klein A. Latinizing the 'national pastime'. *Int J Hist Sport*. 2007;24:296-310. https://doi.org/10.1080/09523360601046029
79. Knowles SB, Marshall SW, Miller T, et al. Cost of injuries from a prospective cohort study of North Carolina high school athletes. *Inj Prev*. 2007;13:416-421. https://doi.org/10.1136/ip.2006.014720
80. Krajnik S, Fogarty KJ, Yard EE, Comstock RD. Shoulder injuries in US high school baseball and softball athletes, 2005–2008. *Pediatrics*. 2010;125:497-501. https://doi.org/10.1542/peds.2009-0961
81. Landon A. *Acquisition and effectiveness of coping strategies used by professional baseball players to manage anxiety and attentional control: a qualitative study* [dissertation]. San Diego, CA: Alliant International University; 2015.
82. Laudner K, Sipes R, Holman A. A comparison of injury rates and game characteristics between non-wood and wood bat usage in high school baseball [abstract]. *Med Sci Sports Exerc*. 2008;40:S234. https://doi.org/10.1249/01.mss.0000322503.71700.28
83. Laudner KG, Sipes RC. A comparison of injury and game characteristics between non-wood and wood baseball bats. *Athl Train Sports Health Care*. 2009;1:222-226. https://doi.org/10.3928/19425864-20090826-04
84. Lee J, Kim LN, Song H, Kim S, Woo S. The effect of glenohumeral internal rotation deficit on the isokinetic strength, pain, and quality of life in male high school baseball players. *Ann Rehabil Med*. 2015;39:183-190. https://doi.org/10.5535/arm.2015.39.2.183
85. Lemez S, Baker J. Do elite athletes live longer? A systematic review of mortality and longevity in elite athletes. *Sports Med Open*. 2015;1:16. https://doi.org/10.1186/s40798-015-0024-x
86. León-Latre M, Moreno-Franco B, Andrés-Esteban EM, et al. Sedentary lifestyle and its relation to cardiovascular risk factors, insulin resistance and inflammatory profile. *Rev Esp Cardiol (Engl Ed)*. 2014;67:449-455. https://doi.org/10.1016/j.rec.2013.10.015
87. Lerch S. The life satisfaction of retired ballplayers. *Baseball Res J*. 1982;11:39-43.
88. Lester D. The "birthday blues" in a sample of Major League Baseball players' suicides [abstract]. *Percept Mot Skills*. 2005;101:382. https://doi.org/10.2466/pms.101.2.382-382
89. Lester D. Suicides among former Major League Baseball players [abstract]. *Percept Mot Skills*. 2004;99:1122. https://doi.org/10.2466/pms.99.3f.1122-1122
90. Lester D, Gunn JF, 3rd. *Suicide in Professional and Amateur Athletes: Incidence, Risk Factors, and Prevention*. Springfield, IL: Charles C. Thomas; 2013.
91. Lester D, Topp R. Major League Baseball performances of players who were later suicides or homicide victims [abstract]. *Percept Mot Skills*. 1989;69:272. https://doi.org/10.2466/pms.1989.69.1.272
92. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci*. 2010;5:69. https://doi.org/10.1186/1748-5908-5-69
93. Levine MA. Effect of smokeless tobacco on cardiovascular risk factors in professional baseball players [journal club]. *Clin J Sport Med*. 1993;3:62.
94. Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012;380:2224-2260. https://doi.org/10.1016/S0140-6736(12)61766-8
95. Liu JN, Garcia GH, Conte S, ElAttrache N, Altchek DW, Dines JS. Outcomes in revision Tommy John surgery in Major League Baseball pitchers. *J Shoulder Elbow Surg*. 2016;25:90-97. https://doi.org/10.1016/j.jse.2015.08.040
96. Macera CA, Hootman JM, Sniezek JE. Major public health benefits of physical activity. *Arthritis Rheum*. 2003;49:122-128. https://doi.org/10.1002/art.10907
97. Mahoney MP. *Alcohol consumption and drug use among former Major League Baseball players* [thesis]. Philadelphia, PA: Temple University; 2002.
98. Marini M, Sarchielli E, Portas MF, et al. Can baseball improve balance in blind subjects? *J Sports Med Phys Fitness*. 2011;51:227-232.
99. Matthews CE, Chen KY, Freedson PS, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. *Am J Epidemiol*. 2008;167:875-881. https://doi.org/10.1093/aje/kwm390
100. Mazoué CG, Andrews JR. Repair of full-thickness rotator cuff tears in professional baseball players. *Am J Sports Med*. 2006;34:182-189. https://doi.org/10.1177/0363546505279916
101. McCue FC, Gieck JH. Pitcher's throwing routine can prevent arm injuries. *First Aider*. 1981;50:12.
102. McDuff DR, Morse ED, White RK. Professional and collegiate team assistance programs: services and utilization patterns. *Clin Sports Med*. 2005;24:943-958. https://doi.org/10.1016/j.csm.2005.02.001
103. McFarland EG, Wasik M. Epidemiology of collegiate baseball injuries. *Clin J Sport Med*. 1998;8:10-13. https://doi.org/10.1097/00042752-199801000-00003
104. Meir RA, Weatherby RP, Rolfe MI. A preliminary investigation into the long-term injury

consequences reported by retired baseball players. *J Sci Med Sport*. 2007;10:187-190. https://doi.org/10.1016/j.jsams.2006.06.002
105. Menon S, Witte KA, Novakovich PM, Andrews JR, Russell EM. Compression shirts decrease pain and improve performance in youth pitchers [abstract]. *Med Sci Sports Exerc*. 2013;45:S511.
106. Morgan-Cooper A, Wasik M, Jernigan J, McFarland EG. Tuberculosis in a young baseball player. *Phys Sportsmed*. 1997;25:112-125. https://doi.org/10.3810/psm.1997.09.1511
107. Murray AD, Daines L, Archibald D, et al. The relationships between golf and health: a scoping review. *Br J Sports Med*. 2017;51:12-19. https://doi.org/10.1136/bjsports-2016-096625
108. Namdari S, Baldwin K, Ahn A, Huffman GR, Sennett BJ. Performance after rotator cuff tear and operative treatment: a case-control study of Major League Baseball pitchers. *J Athl Train*. 2011;46:296-302. https://doi.org/10.4085/1062-6050-46.3.296
109. Nattiv A, Puffer JC. Lifestyles and health risks of collegiate athletes. *J Fam Pract*. 1991;33:585-590.
110. Norton K, Olds T. Morphological evolution of athletes over the 20th century: causes and consequences. *Sports Med*. 2001;31:763-783. https://doi.org/10.2165/00007256-200131110-00001
111. Oja P, Titze S, Kokko S, et al. Health benefits of different sport disciplines for adults: systematic review of observational and intervention studies with meta-analysis. *Br J Sports Med*. 2015;49:434-440. https://doi.org/10.1136/bjsports-2014-093885
112. Oyama S, Register-Mihalik JK, Marshall SW, Mueller FO. Lifetime prevalence of pitching-related shoulder and elbow injuries among collegiate baseball players. *Athl Train Sports Health Care*. 2014;6:105-110. https://doi.org/10.3928/19425864-20140501-03
113. Peters SD, Bullock GS, Goode AP, Garrigues GE, Ruch DS, Reiman MP. The success of return to sport after ulnar collateral ligament injury in baseball: a systematic review and meta-analysis. *J Shoulder Elbow Surg*. 2018;27:561-571. https://doi.org/10.1016/j.jse.2017.12.003
114. Posner M, Cameron KL, Wolf JM, Belmont PJ, Jr., Owens BD. Epidemiology of Major League Baseball injuries. *Am J Sports Med*. 2011;39:1676-1680. https://doi.org/10.1177/0363546511411700
115. Powell JW, Barber-Foss KD. Injury patterns in selected high school sports: a review of the 1995-1997 seasons. *J Athl Train*. 1999;34:277-284.
116. Pytiak AV, Kraeutler MJ, Currie DW, McCarty EC, Comstock RD. An epidemiological comparison of elbow injuries among United States high school baseball and softball players, 2005-2006 through 2014-2015. *Sports Health*. 2018;10:119-124. https://doi.org/10.1177/1941738117736493
117. Reyes C, Leyland KM, Peat G, Cooper C, Arden NK, Prieto-Alhambra D. Association between overweight and obesity and risk of clinically diagnosed knee, hip, and hand osteoarthritis: a population-based cohort study. *Arthritis Rheumatol*. 2016;68:1869-1875. https://doi.org/10.1002/art.39707
118. Robertson PB, Walsh MM, Greene JC. Oral effects of smokeless tobacco use by professional baseball players. *Adv Dent Res*. 1997;11:307-312. https://doi.org/10.1177/08959374970110030101
119. Rothermich MA, Conte SA, Aune KT, Fleisig GS, Cain EL, Jr., Dugas JR. Incidence of elbow ulnar collateral ligament surgery in collegiate baseball players. *Orthop J Sports Med*. 2018;6:2325967118764657. https://doi.org/10.1177/2325967118764657
120. Saint Onge JM, Rogers RG, Krueger PM. Major League Baseball players' life expectancies. *Soc Sci Q*. 2008;89:817-830. https://doi.org/10.1111/j.1540-6237.2008.00562.x
121. Sakata J, Nakamura E, Suzuki T, et al. Efficacy of a prevention program for medial elbow injuries in youth baseball players. *Am J Sports Med*. 2018;46:460-469. https://doi.org/10.1177/0363546517738003
122. Saper MG, Pierpoint LA, Liu W, Comstock RD, Polousky JD, Andrews JR. Epidemiology of shoulder and elbow injuries among United States high school baseball players: school years 2005-2006 through 2014-2015. *Am J Sports Med*. 2018;46:37-43. https://doi.org/10.1177/0363546517734172
123. Schuring N, Kerkhoffs G, Gray J, Gouttebarge V. The mental wellbeing of current and retired professional cricketers: an observational prospective cohort study. *Phys Sportsmed*. 2017;45:463-469. https://doi.org/10.1080/00913847.2017.1386069
124. Seagrave RA, 3rd, Perez L, McQueeney S, Toby EB, Key V, Nelson JD. Preventive effects of eccentric training on acute hamstring muscle injury in professional baseball. *Orthop J Sports Med*. 2014;2:2325967114535351. https://doi.org/10.1177/2325967114535351
125. Severson HH, Klein K, Lichtensein E, Kaufman N, Orleans CT. Smokeless tobacco use among professional baseball players: survey results, 1998 to 2003. *Tob Control*. 2005;14:31-36. https://doi.org/10.1136/tc.2004.007781
126. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS. Incidence of injuries in high school softball and baseball players. *J Athl Train*. 2011;46:648-654. https://doi.org/10.4085/1062-6050-46.6.648
127. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS. Incidence of overall and upper extremity injuries in high school baseball and softball players [abstract]. *Med Sci Sports Exerc*. 2010;42:S471. https://doi.org/10.1249/01.MSS.0000385047.18265.c4
128. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med*. 2011;39:1997-2006. https://doi.org/10.1177/0363546511408876
129. Shitara H, Yamamoto A, Shimoyama D, et al. Shoulder stretching intervention reduces the incidence of shoulder and elbow injuries in high school baseball players: a time-to-event analysis. *Sci Rep*. 2017;7:45304. https://doi.org/10.1038/srep45304
130. Sinusas K, Coroso JG. A 10-yr study of smokeless tobacco use in a professional baseball organization. *Med Sci Sports Exerc*. 2006;38:1204-1207. https://doi.org/10.1249/01.mss.0000227303.80783.46
131. Smith G. Birth month is not related to suicide among Major League Baseball players. *Percept Mot Skills*. 2011;112:55-60. https://doi.org/10.2466/07.PMS.112.1.55-60
132. Solberg J, Ringer R. Performance-enhancing drug use in baseball: the impact of culture. *Ethics Behav*. 2011;21:91-102. https://doi.org/10.1080/10508422.2011.551466
133. Song A, Severini T, Allada R. How jet lag impairs Major League Baseball performance. *Proc Natl Acad Sci U S A*. 2017;114:1407-1412. https://doi.org/10.1073/pnas.1608847114
134. Spiker DD. *An assessment and treatment of precompetitive state anxiety among collegiate baseball players* [dissertation]. Morgantown, WV: West Virginia University; 1982.
135. Stansfeld S, Smuk M, Onwumere J, et al. Stressors and common mental disorder in informal carers – an analysis of the English Adult Psychiatric Morbidity Survey 2007. *Soc Sci Med*. 2014;120:190-198. https://doi.org/10.1016/j.socscimed.2014.09.025
136. Strang J. Death matters: understanding heroin/opiate overdose risk and testing potential to prevent deaths. *Addiction*. 2015;110 suppl 2:27-35. https://doi.org/10.1111/add.12904
137. Strine TW, Chapman DP, Balluz LS, Moriarty DG, Mokdad AH. The associations between life satisfaction and health-related quality of life, chronic illness, and health behaviors among U.S. community-dwelling adults. *J Community Health*. 2008;33:40-50. https://doi.org/10.1007/s10900-007-9066-4
138. Tanimaru JH, Dos Santos ALP. Study on the quality of life at a baseball performance center. *J Phys Educ Sport*. 2016;16:365-373. https://doi.org/10.7752/jpes.2016.02058
139. Thigpen CA, Bailey LB, Kissenberth MJ, Noonan TJ, Hawkins RJ, Shanley E. Effectiveness of a preseason prevention program on arm injury risk factors: an [sic] randomized control trial in adolescent pitchers [abstract]. *Orthop J Sports Med*. 2016;4:2325967116S2325900066. https://doi.org/10.1177/2325967116S00066
140. Tynes JR. Performance enhancing substances. Effects, regulations, and the pervasive efforts to control doping in Major League Baseball. *J Leg Med*. 2006;27:493-509. https://doi.org/10.1080/01947640601021113
141. Wade D. *Anxiety, progressive muscle relaxation training, and recuperation of a baseball pitcher's arm* [thesis]. Fresno, CA: Alliant International University; 2009.

142. Walsh M, Hilton JF, Ellison J, et al. Smokeless tobacco cessation among high school baseball athletes [abstract]. *J Dent Res*. 2000;79:243. https://doi.org/10.1177/0022034500079S108

143. Walsh M, Hilton JF, Ellison J, et al. Spit tobacco cessation among high school baseball athletes [abstract]. *J Dent Res*. 1998;77:832. https://doi.org/10.1177/0022034598077S201

144. Walsh MM, Ellison J, Hilton JF, Chesney M, Ernster VL. Spit (smokeless) tobacco use by high school baseball athletes in California. *Tob Control*. 2000;9 suppl 2:II32-II39. https://doi.org/10.1136/tc.9.suppl_2.ii32

145. Walsh MM, Hilton JF, Ellison JA, et al. Spit (smokeless) tobacco intervention for high school athletes: results after 1 year. *Addict Behav*. 2003;28:1095-1113. https://doi.org/10.1016/s0306-4603(02)00228-9

146. Walsh MM, Hilton JF, Ernster VL, Masouredis CM, Grady DG. Prevalence, patterns, and correlates of spit tobacco use in a college athlete population. *Addict Behav*. 1994;19:411-427. https://doi.org/10.1016/0306-4603(94)90064-7

147. Walsh MM, Hilton JF, Masouredis CM, Gee L, Chesney MA, Ernster VL. Smokeless tobacco cessation intervention for college athletes: results after 1 year. *Am J Public Health*. 1999;89:228-234. https://doi.org/10.2105/ajph.89.2.228

148. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *CMAJ*. 2006;174:801-809. https://doi.org/10.1503/cmaj.051351

149. Warren GW, Cummings KM. Tobacco and lung cancer: risks, trends, and outcomes in patients with cancer. *Am Soc Clin Oncol Educ Book*. 2013:359-364. https://doi.org/10.1200/EdBook_AM.2013.33.359

150. Waterbor J, Cole P, Delzell E, Andjelkovich D. The mortality experience of Major-League Baseball players. *N Engl J Med*. 1988;318:1278-1280. https://doi.org/10.1056/NEJM198805123181917

151. Whittaker JL, Woodhouse LJ, Nettel-Aguirre A, Emery CA. Outcomes associated with early post-traumatic osteoarthritis and other negative health consequences 3–10 years following knee joint injury in youth sport. *Osteoarthritis Cartilage*. 2015;23:1122-1129. https://doi.org/10.1016/j.joca.2015.02.021

152. Williams JZ, Singichetti B, Li H, Xiang H, Klingele KE, Yang J. Epidemiological patterns of initial and subsequent injuries in collegiate football athletes. *Am J Sports Med*. 2017;45:1171-1178. https://doi.org/10.1177/0363546516685317

153. Wilson AT, Pidgeon T, DaSilva MF, Morrell N. Trends in elbow ulnar collateral ligament reconstruction in professional baseball pitchers: level 4 evidence [abstract]. *J Hand Surg*. 2015;40:e23-e24. https://doi.org/10.1016/j.jhsa.2015.06.044

154. Wisniewski JF, Bartolucci AA, Beisel JG, Mann KR. Characteristics of the professional baseball smokeless tobacco user [abstract]. *J Dent Res*. 1990;69:259. https://doi.org/10.1177/0022034590069S101

155. Wisniewski JF, Curcio BF, Bartolucci AA, Fox LM, Lovell J. Patterns of nicotine and alcohol usage in professional baseball players [abstract]. *J Dent Res*. 1996;75:517.

156. Yoneda M, Hayashida K, Hirooka A. Arthroscopically assisted surgical treatment of painful throwing shoulder in baseball players. *Surgery of the Shoulder: Proceedings of the 6th International Congress on Surgery of the Shoulder*. Helsinki, Finland/Stockholm, Sweden: Elsevier; 1995:289-297.

157. Zachazewski J, Silvers HJ, Li B, et al. Hamstring injuries in Major and Minor League Baseball: are they preventable? [abstract]. *Orthop J Sports Med*. 2016;4:2325967116S2325900182. https://doi.org/10.1177/2325967116S00182

APPENDIX A

SEARCH STRATEGIES

MEDLINE, Embase, CINAHL, Cochrane Library, PsycINFO, PEDro, www.clinicaltrials.gov, and the ISRCTN Registry
baseball*

SPORTDiscus
(Baseball* or pitcher* or catcher* or hitter* or "position player*" or outfielder* or shortstop* or "first base*" or "third base*") AND (health* or tobacco or smoke* or smoking or alcohol* or illness or injur* or fitness* or mortalit* or death or morbidit* or inciden* or prevalen* or pain or wellbeing or "well being" or "quality of life" OR *QOL or "physical activity" or psych or depression or anxiet* or mental disorders or stress* or social or neurological or respiratory or metabolic or cardiovascular or longevity or musculoskeletal or osteoarthriti* or mood or rehab* or surger* or hamstring* or quadricep* or adductor or calf or plantar or shoulder or elbow or "ulnar collateral reconstruction" or "anterior cruciate ligament" or ACL or UCL or hand or foot or spine or neck or back or labrum or arm or forearm or concussion or head or TBI) NOT (cadaver* or "in situ" or "in vitro" or animals)

Web of Science
(Baseball* or pitcher* or catcher* or hitter* or "position player*" or outfielder* or shortstop* or "first base*" or "third base*") AND (health* or tobacco or smoke* or smoking or alcohol* or illness or injur* or fitness* or mortalit* or death or morbidit* or inciden* or prevalen* or pain or wellbeing or "well being" or "quality of life" OR *QOL or "physical activity" or psych or depression or anxiet* or mental disorders or stress* or social or neurological or respiratory or metabolic or cardiovascular or longevity or musculoskeletal or osteoarthriti* or mood or rehab* or surger* or hamstring* or quadricep* or adductor or calf or plantar or shoulder or elbow or "ulnar collateral reconstruction" or "anterior cruciate ligament" or ACL or UCL or hand or foot or spine or neck or back or labrum or arm or forearm or concussion or head or TBI) NOT (cadaver* or "in situ" or "in vitro" or animals)

Scopus
((TITLE-ABS-KEY (baseball* OR pitcher* OR catcher* OR hitter* OR "position player*" OR outfielder* OR shortstop* OR "first base*" OR "third base*")) AND NOT (TITLE-ABS-KEY (cadaver* OR "in situ" OR "in vitro" OR animals))) AND (((TITLE-ABS-KEY (health* OR tobacco OR smoke* OR smoking OR alcohol* OR illness OR injur* OR fitness* OR mortalit* OR death OR morbidit* OR inciden* OR prevalen* OR "quality of life" OR *QOL OR "physical activity" OR psych* OR "mental disorders" OR cardiovascular OR respiratory or metabolic OR longevity OR wellbeing OR "well being" OR depression OR anxiet* OR mental AND disorders OR stress* OR osteoarthriti*)) OR (TITLE-ABS-KEY (musculoskeletal OR labrum OR hamstring* OR quadricep* OR adductor OR calf OR plantar OR shoulder OR elbow OR hand OR foot OR acl OR "anterior collateral ligament" OR "ulnar collateral ligament" OR UCL OR hamstring*)) OR (TITLE-ABS-KEY (mood OR rehab* OR surger* OR "tommy john" OR "ulnar collateral ligament reconstruction" OR "rotator cuff" OR labrum))) AND NOT (TITLE-ABS-KEY (cadaver* OR "in situ" OR "in vitro" OR animals))) AND (LIMIT-TO (LANGUAGE, "English"))

ProQuest
((ti(Baseball* or pitcher* or catcher* or hitter* or "position player*" or outfielder* or shortstop* or "first base*" or "third base*") AND (health* or tobacco or smoke* or smoking or alcohol* or illness or injur* or fitness* or mortalit* or death or morbidit* or inciden* or prevalen* or pain or wellbeing or "well being" or "quality of life" OR *QOL or "physical activity" or psych or depression or anxiet* or mental disorders or stress* or social or neurological or respiratory or metabolic or cardiovascular or longevity or musculoskeletal or osteoarthriti* or mood or rehab* or surger* or hamstring* or quadricep* or adductor or calf or plantar or shoulder or elbow or "ulnar collateral reconstruction" or "anterior cruciate ligament" or ACL or UCL or hand or foot or spine or neck or back or labrum or arm or forearm or concussion or head or TBI))) NOT (ti(cadaver* OR "in situ" OR "in vitro" OR animals) OR ab(cadaver* OR "in situ" OR "in vitro" OR animals) OR diskw(cadaver* OR "in situ" OR "in vitro" OR animals))

Google Scholar
allintitle: (baseball| pitcher|catcher|hitter|"position player"|outfielder|shortstop|"first base"|"third base") AND (health|tobacco|smoke|smokeless|alcohol|illness|injury|fitness|mortality|death|morbidity|incidence|prevalence|pain|"quality of life"|wellbeing|"well being"|depression|anxiety|"mental disorder"|stress|osteoarthritis|mood|QOL|"quality of life"|"rotator cuff"|leg|thigh|back|wrist|shoulder|elbow|"ulnar collateral ligament"|trunk|torso|foot|ankle|knee|"anterior cruciate ligament"|neck|spine|hamstring|quadriceps|calf|plantar|forearm|"tommy john"|labrum)

APPENDIX B

COUNT OF STUDIES BY BODY PART OR CONDITION

Body Part or Condition	Value[a]
Acromioclavicular joint	4 (<1)
Ankle	4 (<1)
Commotio cordis	5 (<1)
Dental	1 (<1)
Elbow	218 (37)
Eye	4 (<1)
Face	5 (<1)
Foot	5 (<1)
Forearm	1 (<1)
Hand	12 (2)
Hip	6 (<1)
Knee	11 (2)
Leg	1 (<1)
Neurological	16 (3)
Shin	2 (<1)
Shoulder	197 (34)
Skin	5 (<1)
Spine	22 (4)
Testicular	2 (<1)
Thigh	8 (1)
Thoracic outlet	2 (<1)
Total body	46 (8)
Vascular	20 (3)
Viscera	1 (<1)
Wrist	1 (<1)

[a]*Values are n (percent) of musculoskeletal health studies (n = 583). Some studies are counted more than once due to multiple outcomes.*

FIGURE 1. Photograph of gastrocnemius bulge during a heel raise.

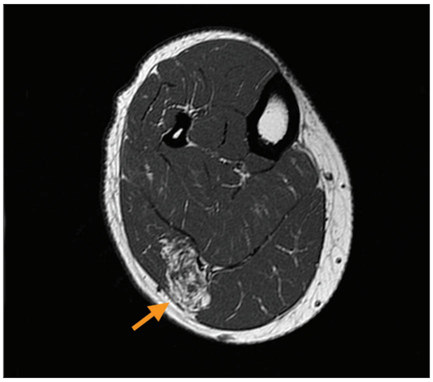

FIGURE 3. Axial, T1-weighted magnetic resonance image at the proximal to mid tibial diaphysis level demonstrating an intramuscular soft tissue mass, located within the medial aspect of the lateral gastrocnemius. The mass contains heterogeneous, serpentine increased T1 signal, representing a combination of dilated vascular channels with slow-flowing blood and surrounding hamartomatous stroma (arrow).

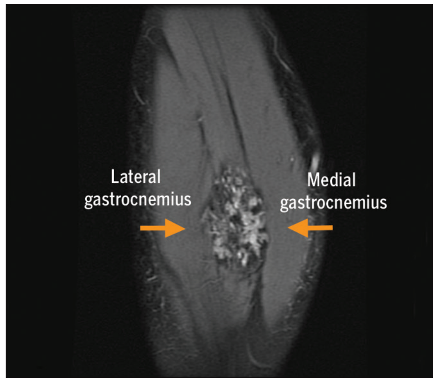

FIGURE 4. Coronal, fat-suppressed, proton-density weighted magnetic resonance image demonstrating serpentine branching vessels within the intramuscular mass, consistent with a venous malformation (between arrows).

Venous Malformation in the Gastrocnemius Muscle

JOSIAH FAVILLE, PT, DPT, OCS, COMT, FAAOMPT, *Therapeutic Associates Physical Therapy, Salem, OR; North American Institute of Orthopaedic Manual Therapy, Eugene, OR.*
STEVE KARAS, PT, DSc, CMPT, OCS, *Physical Therapy Program, Chatham University, Pittsburgh, PA; North American Institute of Orthopaedic Manual Therapy, Eugene, OR.*
LEON TOYE, MD, *Radsource, Brentwood, TN.*

A 35-YEAR-OLD WOMAN WAS REferred to physical therapy by her primary care physician for right calf pain with gradual onset over 1 year. Pain was exacerbated with prolonged walking, rising on toes, and participating in martial arts. She denied a history of lower extremity injury.

Examination revealed symmetrical calves with normal coloration, unremarkable neurovascular signs, and full strength. At the right calf, a bulge became visible between the gastrocnemius muscle bellies during a single-leg heel raise (**FIGURE 1**). This action reproduced pain, as did palpation of the mass. Initial differential diagnosis included fascial defect with subsequent muscle herniation,[1,2] gastrocnemius partial tear, and popliteal vascular dysfunction.

Heel-raise symptoms improved with manual approximation of the gastrocnemius heads, and a diagnosis of fascial insufficiency with muscle herniation was made. As approximation reduced symptoms, approximation taping was provided, along with soft tissue mobilization and education on activity modification. After 6 visits over 2 months, when taping was withdrawn, heel raising remained symptomatic and no clinical improvement in bulging or pain with palpation was noted.

Given limited progress, the patient was referred to an orthopaedist. Radiographs revealed several phleboliths (**FIGURE 2**, available at www.jospt.org), and magnetic resonance imaging revealed an 8.7 × 3.0 × 1.7-cm intramuscular vascular mass within the lateral gastrocnemius (**FIGURES 3** and **4**).[3] Surgical resection of the mass was completed with scissor dissection, cautery, and suture ligation. After 4 weeks of postoperative rehabilitation, her pain with walking resolved, and after 3 months she demonstrated normal calf strength and returned to martial arts without limitation. ◉ *J Orthop Sports Phys Ther 2020;50(2):110. doi:10.2519/jospt.2020.9091*

References

1. Bergmann G, Ciritsis BD, Wanner GA, Simmen HP, Werner CM, Osterhoff G. Gastrocnemius muscle herniation as a rare differential diagnosis of ankle sprain: case report and review of the literature. *Patient Saf Surg*. 2012;6:5. https://doi.org/10.1186/1754-9493-6-5
2. Cormier DJ, Gellhorn AC, Singh JR. Soleus muscle herniation with magnetic resonance imaging and ultrasound correlation in a female long-distance runner: a case report. *PM R*. 2017;9:529-532. https://doi.org/10.1016/j.pmrj.2016.10.021
3. Flors L, Leiva-Salinas C, Maged IM, et al. MR imaging of soft-tissue vascular malformations: diagnosis, classification, and therapy follow-up. *Radiographics*. 2011;31:1321-1340; discussion 1340-1341. https://doi.org/10.1148/rg.315105213

JOEL T. FULLER, PT, PhD[1] • MATTHEW LYNAGH, PT[2] • BRETT TARCA, AEP[2] • ANDREW ZACHARIA, PT[2]
ALEX TOWNSLEY, PT[2] • CARA GLEESON, PT[2] • STEVEN MILANESE, PT, PhD[2] • SAMUEL CHALMERS, ASpS1, PhD[3,4]

Functional Movement Screen Pain Location and Impact on Scoring Have Limited Value for Injury Risk Estimation in Junior Australian Football Players

Australian football is a popular junior sport in Australia,[2] and is associated with a high incidence of contact and noncontact injuries.[22] There have been several observational studies investigating the incidence and characteristics of junior Australian football injuries[22,33,35]; however, there is a need to explore modifiable injury risk factors. Identification of modifiable risk factors is an important progression of previous junior Australian football injury surveillance research, and is consistent with the well-established Translating Research into Injury Prevention Practice framework (TRIPP).[14] Screening to identify movement characteristics that are associated with injury is common in team sports such as Australian football.[26] However, there is no consensus on the best approach to movement screening, and all approaches lack consistent evidence to support its use for injury prevention.[26]

OBJECTIVE: To describe the location and severity of pain during Functional Movement Screen (FMS) testing in junior Australian football players and to investigate its effect on FMS composite score and injury risk.

DESIGN: Prospective cohort study.

METHODS: Junior male Australian football players (n = 439) completed preseason FMS testing. Pain location and severity (on a 0-to-10 numeric pain-rating scale [NPRS]) were assessed for painful subtests. The FMS composite score was calculated using 3 scoring approaches: "traditional," a score of zero on painful subtests; "moderate," a score of zero on painful subtests if an NPRS pain severity was greater than 4; and "raw," did not adjust painful FMS subtest scores. Players were monitored throughout the competitive season and considered injured when 1 or more matches were missed due to injury.

RESULTS: One hundred seventy players reported pain during FMS testing. The pain-scoring approach affected mean composite score values (raw, 14.9; moderate, 14.5; traditional, 13.6; $P<.001$). Sixty-eight percent of pain was mildly severe (NPRS of 4 or less). Back pain (50%) was more common than upper-limb (24%) or lower-limb (26%) pain ($P<.001$). Upper-limb pain was associated with a small increase in injury risk (hazard ratio = 1.59, $P = .023$). No other FMS pain location influenced injury risk, nor did pain severity ($P>.280$). The FMS composite score was not associated with injury risk, regardless of pain-scoring approach ($P \geq .500$).

CONCLUSION: Pain was common during FMS testing in junior Australian football players and had a notable effect on the FMS composite score, but minimal effect on subsequent injury risk. *J Orthop Sports Phys Ther 2020;50(2):75-82. Epub 17 Sep 2019. doi:10.2519/jospt.2020.9168*

KEY WORDS: *adolescent, athlete, risk, sport*

The Functional Movement Screen (FMS) is arguably the most researched approach to movement screening in team sports,[26] although most research has been in adult populations rather than in junior athletes.[27] This research has typically investigated the association between the total (composite) score each athlete achieves across the 7 FMS subtests and the athlete's risk of subsequent injury. Notably, recent systematic reviews have reported mixed results, with one describing the FMS as a valuable screening tool[5] and others highlighting conflicting evidence[29] or questioning the diagnostic sensitivity of the test.[11] One reason for the mixed results could be the way that pain during FMS testing is integrated into the composite score (painful movements are scored zero, regardless of movement quality or pain severity[8,9]) and the potential for pain prevalence to differ across study populations. For example, 38% of junior Australian football players reported pain during FMS testing,[15] compared to less

[1]Department of Health Professions, Faculty of Medicine and Health Sciences, Macquarie University, Macquarie Park, Australia. [2]International Centre for Allied Health Evidence, University of South Australia, Adelaide, Australia. [3]Exercise and Sport Science, School of Health Sciences, The University of Sydney, Lidcombe, Australia. [4]Sport and Exercise Science, School of Science and Health, Western Sydney University, Penrith, Australia. The study was approved by the University of South Australia Human Research Ethics Committee (protocol number 33950). The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Joel Fuller, Faculty of Medicine and Health Sciences, Macquarie University, 75 Talavera Road, Macquarie Park 2109 NSW, Australia. E-mail: joel.fuller@mq.edu.au

than 20% of junior soccer players.[24] Notably, despite the importance of pain to FMS scoring, very few FMS studies report pain prevalence or its relationship to injury risk estimation,[27] and no studies have investigated the location and severity of pain across FMS subtests. Understanding the location and severity of pain during FMS testing could provide insights into its relevance to movement screening.

The few studies that have investigated the relationship between pain during FMS testing and injury have reported conflicting findings. Two large-scale prospective studies involving over 2000 adult soldiers indicated that there was a small association between pain during FMS testing and subsequent injury risk (relative risk of 1.6[1] and an odds ratio of 1.3 to 2.1 across subtests[6]). Two studies with smaller sample sizes involving junior Australian football athletes reported that pain during FMS testing had a small, significant association with retrospectively reported injury (odds ratio = 2.0),[15] but a nonsignificant association with prospectively reported injury (hazard ratio [HR] = 1.5).[7] These mixed results do not indicate a clear solution to how pain during FMS testing should be incorporated into FMS scoring for injury risk estimation. The null finding in the prospective junior Australian football study[7] suggests that the traditional approach of heavily penalizing subtest scores based on the presence of pain may weaken any potential relationships between the FMS composite score and subsequent injury (ie, pain and movement quality could be considered as independent predictor variables). In contrast, the small association between pain during FMS testing and subsequent injury in soldiers[6] suggests that lower scores for painful movements may strengthen relationships with subsequent injury. Clearly, there is a need to investigate the interplay between pain and movement quality in FMS-based injury risk estimation in order to inform future research and clinical use.

The aims of the present study were (1) to describe the location and severity of the pain reported by junior Australian football players during FMS testing, (2) to investigate the relationship between pain during FMS testing and subsequent injury, and (3) to investigate the influence of different scoring approaches to pain during FMS testing on the relationship between FMS score and subsequent injury. It was hypothesized that players reporting pain during FMS testing would be more likely to sustain a subsequent injury, regardless of location, when the reported pain severity on a 0-to-10 numeric pain-rating scale was 5 or more (ie, moderate pain or greater), and that the FMS composite score would be associated with subsequent injury risk when painful FMS subtests were scored zero only when pain severity was moderate or greater.

METHODS

A prospective cohort study was undertaken across 2 consecutive competitive seasons (2017 and 2018) in the junior male (under 18 years old) South Australian National Football League (SANFL) competition. The study was approved by the University of South Australia Human Research Ethics Committee (protocol number 33950). Players were eligible for inclusion if they were registered with 1 of the 8 competing clubs and were injury free at the time of study entry. Only data from the second season were included for players who competed in both seasons. This avoided double counting of participants and statistical issues associated with dependence across some, but not all, observations. The second season was chosen over the first season because the SANFL under-18 competition consists predominantly of players who are in their final year of under-18 age eligibility (ie, "senior year"). Therefore, the second season of participation was believed to be more representative of the competition than the first season. Eligible players provided written informed consent or assent (including parent or guardian consent if the players were younger than 18 years of age) to participate, and the rights of all participants were protected.

Baseline movement and previous injury screening was completed during an annual preseason competition-wide fitness testing combine. The combine occurred over 3 separate days, after teams had completed at least 8 weeks of preseason training. All participants self-reported whether they missed any matches due to injury in the previous competitive season by using a standardized report form. A "missed matches only" injury definition was used to improve the accuracy and precision of the recall information, and is consistent with the injury definition used by the Australian Football League and previous injury surveillance in the same cohort.[30,35] Additional information about previous injuries (ie, body location and diagnosis) was not incorporated into the study due to poor validity.[16] Movement screening occurred after players had completed warm-up activities that were organized by fitness staff from their respective clubs. Eight testers were responsible for assessing the full FMS testing battery in all participating players. Testers were qualified physical therapists, exercise physiologists, or strength and conditioning coaches with previous FMS experience. All testers had completed level 1 FMS certification training. A previous systematic review demonstrated acceptable reliability for the FMS.[28] Additionally, each tester was responsible for 1 testing station, involving either 1 or 2 subtests, to reduce the potential for interrater differences to influence overall FMS findings.

The FMS testing battery has been described in detail previously.[8,9] The testing battery consists of 7 movement subtests that are scored from 1 to 3 (deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability) and 3 pain-clearing tests (shoulder combined internal rotation and flexion, end-range spinal extension [press-up], and end-range spinal flexion). A score of 3 indicates no compensatory movement, a score of 2 indicates 1 or more compensatory movements, and a score of 1 indicates that the player was unable to complete the required task for that subtest. The lowest score across left and right sides is used for subtests that have a left and right component. After each subtest or accompanying clearing test, players were asked if they experienced pain. Information about pain location and severity on a 0-to-10 numeric pain-rating scale was obtained for all reported occurrences of pain. Pain severity was considered mild (1-4), moderate (5-6), or severe (7-10), in accordance with previous pain research.[20] The FMS composite score was calculated for each player based on 3 different approaches to pain scoring: (1) "traditional" composite score was the sum of all subtest scores when all painful subtests were scored zero, regardless of pain severity; (2) "moderate" composite score was the sum of all subtest scores when painful subtests were scored zero only when pain was moderate or severe; and (3) "raw" composite score was the sum of all subtest scores when no scoring adjustment was made to painful subtests.

Prospective injury surveillance was undertaken for all players during all 18 competitive-season matches. The manager of each team tracked the match participation of all participating players registered with their club to determine the total exposure of each player (ie, number of weeks participating with each club). This player tracking system was also used to notify the research team of any players who missed a match due to injury. Injuries that occurred during training and matches were included in the study, provided that the injury caused a player to miss a subsequent match. Club medical staff provided information about injury location and mechanisms. The injury locations were (1) head and neck region, (2) upper-limb region (ie, shoulder, arm, elbow, forearm, wrist, and hand), (3) trunk and back region (ie, rib, chest wall, and the thoracic, lumbar, and sacral spines), and (4) lower-limb region (ie, hip, groin, thigh, knee, shin, ankle, and foot). Both all-cause and noncontact injuries were investigated. Noncontact injuries were defined as resulting from mechanisms that did not involve contact with another player or with a fixed object (ie, the goalpost), or being struck by a ball. Noncontact injury mechanisms included overuse, jumping, falling, slipping, tripping, and overextension. In contrast to the established Australian Football League surveillance system, illnesses were not considered injuries.

Statistical analyses were performed using R Version 3.2.1 (R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were used to investigate the prevalence, severity, and location of pain across the FMS subtests. Proportions were compared using chi-square tests. Repeated-measures analysis of variance was used to compare FMS composite scores across the different pain-scoring approaches. Huynh-Feldt adjustment of degrees of freedom was used to account for sphericity violation. Residual plots were used to assess normality. Cox proportional hazard regression was used to investigate the relationship between predictor variables and subsequent injury (all-cause and noncontact injury mechanisms were analyzed separately). The number of competition weeks until first injury was considered the survival time. For the noncontact injury analysis, players who sustained a contact injury were considered censored at the point of injury. The predictor variables in the univariable analysis included previous injury, FMS pain (pain presence, severity, and location were considered), and FMS composite score of 14 or less (based on the traditional, moderate, and raw composite score scoring approaches). When multiple statistically significant predictor variables were identified with univariable analysis, they were considered within a multivariable Cox proportional hazard regression model. When pain locations were identified as statistically significant predictor variables, the relationships with specific injury locations were also considered (ie, upper-limb FMS pain as a predictor of subsequent upper-limb injury). For these analyses, players who sustained an injury to a different location or an unknown location were considered censored at the point of injury. Sensitivity and specificity were calculated using 2-by-2 contingency tables for statistically significant predictor variables. Censored players were not included in the 2-by-2 contingency tables. *P* values less than .05 were considered statistically significant.

RESULTS

Twenty players were excluded because they were injured at the time of preseason testing. A total of 439 players met the eligibility criteria and participated in the study across the 2 seasons (mean ± SD age, 17.3 ± 0.6 years; height, 182 ± 7 cm; body mass, 75.7 ± 8.5 kg). All 439 eligible participants were included in the analysis. No players were lost to follow-up. A total of 271 players were not injured during the season and were followed for the full 18 matches. The remaining players were followed up for 8 ± 5 matches until their first injury.

A total of 170 (39%) players reported pain during at least 1 FMS subtest. The trunk stability push-up (14%), press-up clearing test (13%), and deep squat (12%) subtests were associated with the highest proportion of painful tests (P<.001). Pain was most often reported in the back (50%), compared to the upper limbs (24%) or lower limbs (26%) (P<.001). A summary of the pain locations across FMS subtests is presented in **FIGURE 1**. Overall pain severity was 3.4 ± 1.5, with mean pain severity ranging from 2.3 ± 1.0 (hurdle step) to 4.2 ± 1.5 (rotary stability) across subtests. Overall pain severity was 3.4 ± 1.6 for the back, the upper limb, and the lower limb. Most pain reports were of mild (68%) or moderate (26%) severity, with only minimal reports of severe pain (6%). There was a main effect of pain-scoring approaches on the FMS composite score (raw composite score greater than moderate composite score greater than traditional composite score; P<.001). Mean composite scores were

14.9 ± 1.8, 14.5 ± 2.1, and 13.6 ± 2.7 for the raw, moderate, and traditional scoring approaches, respectively.

One hundred sixty-eight players missed a match due to injury during the competitive season. There were 79 lower-limb injuries, 35 upper-limb injuries, 16 back injuries, 18 head or neck injuries, and 20 injuries for which injury location information was not available. Self-reported previous injury (sensitivity, 52%; specificity, 62%) and upper-limb FMS pain (sensitivity, 17%; specificity, 90%) were the only significant predictors of all-cause injuries based on univariable analysis (**TABLE 1**). The associated effect sizes were small. When previous injury and upper-limb FMS pain were considered in a multivariable analysis (**FIGURE 2**), previous injury remained a significant predictor of all-cause injury (HR = 1.54; 95% confidence interval [CI]: 1.11, 2.15; *P* = .011), but upper-limb FMS pain did not (HR = 1.49; 95% CI: 0.79, 2.81; *P* = .221). The combination of upper-limb FMS pain and previous injury was associated with a moderate increase in all-cause injury risk (HR = 2.35; 95% CI: 1.40, 3.94; *P* = .001; sensitivity, 11%; specificity, 96%). Similar effects were evident when upper-limb injury was the outcome in a multivariable analysis that included previous injury (HR = 1.66; 95% CI: 0.80, 3.43; *P* = .175) and upper-limb FMS pain (HR = 1.99; 95% CI: 0.57, 6.91; *P* = .281) as predictor variables.

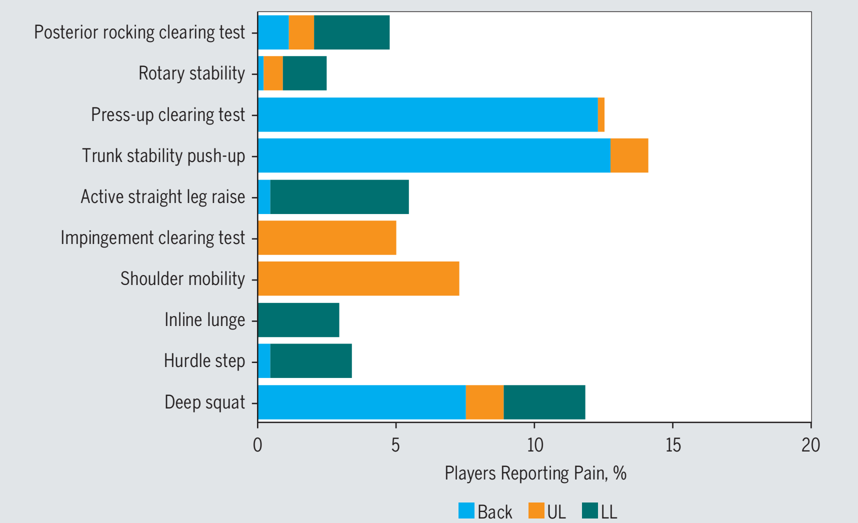

FIGURE 1. The proportion of back, UL, and LL pain reported by all players across Functional Movement Screen subtests. Abbreviations: LL, lower limb; UL, upper limb.

TABLE 1 — Association Between Predictor Variables and Subsequent All-Cause Injury, Based on Univariable Analysis

Predictor Variable	Hazard Ratio[a]	Descriptor	*P* Value
Previous injury	1.59 (1.18, 2.15)	Small	.003[b]
Pain	1.16 (0.85, 1.57)	Trivial	.354
Mild pain	1.17 (0.83, 1.65)	Trivial	.380
Moderate pain	1.15 (0.69, 1.89)	Trivial	.598
Severe pain	1.08 (0.40, 2.94)	Trivial	.879
Upper-limb pain	1.59 (1.07, 2.37)	Small	.023[b]
Lower-limb pain	0.83 (0.53, 1.32)	Trivial	.438
Back pain	1.09 (0.77, 1.54)	Trivial	.643
CS-traditional[c]: score, ≤14	0.96 (0.71, 1.31)	Trivial	.820
CS-moderate[d]: score, ≤14	0.90 (0.66, 1.22)	Trivial	.500
CS-raw[e]: score, ≤14	0.91 (0.66, 1.24)	Trivial	.533

Abbreviation: CS, composite score.
[a]*Values in parentheses are 95% confidence interval.*
[b]*Statistically significant (P<.05).*
[c]*The sum of all subtest scores when painful subtests were scored zero.*
[d]*The sum of all subtest scores when painful subtests were scored zero, but only when pain was of moderate or greater severity.*
[e]*The sum of all subtest scores when no scoring adjustment was made to painful subtests.*

Confirmed noncontact injuries were sustained by 41 players during the in-season period. Information about injury mechanism was not available for 61 injured players who were considered censored at the time of injury. Previous injury (sensitivity, 51%; specificity, 62%) and upper-limb FMS pain (sensitivity, 20%; specificity, 88%) were associated with similar effect-size magnitudes for noncontact (HR = 1.52 and 1.83, respectively) (**TABLE 2**) and all-cause injuries (HR = 1.59 and 1.59, respectively), but the effects were not statistically significant for noncontact injuries (**TABLE 2**). The presence of severe FMS pain was associated with a nonsignificant moderate effect on noncontact injuries (**TABLE 2**) (sensitivity, 5%; specificity, 98%). The CI for the effect was not precise and ranged from a small protective effect to a very large harmful effect on noncontact injury risk (**TABLE 2**).

DISCUSSION

Pain was commonly reported by junior Australian football players during FMS testing, with back pain being twice as common as upper- and lower-limb pain, and most pain being of mild severity. The FMS composite score was affected by the pain-scoring approach, with scores being higher when painful subtests were unadjusted or adjusted only when pain severity was moderate or greater. Contrary to our hypothesis, most pain characteristics were not associated with subsequent injury risk, with only upper-limb pain demonstrating a small, significant association with injury. Additionally, the FMS composite score demonstrated no relationship with subsequent injury risk, regardless of how painful subtests were incorporated into the scoring system. As a result, the FMS composite score and reporting of pain have limited efficacy as injury risk estimation tools in junior Australian football players.

Studies investigating modifiable injury risk factors (TRIPP stage 2) are important to progressing the existing injury prevention research in junior Australian football, which has a well-established injury profile (TRIPP stage 1).[22,33,35] The FMS has previously demonstrated mixed results as a screening tool for identifying modifiable risk factors.[29] To the authors' knowledge, the present study is the first to investigate whether different approaches to scoring pain during FMS testing influence the efficacy of the FMS as an injury estimation tool. Optimizing the FMS pain-scoring approach is important because FMS pain is common in junior Australian football players and, potentially, in other sporting cohorts. Furthermore, pain has a large effect on FMS scoring, but the rationale for this has been previously unexplored. The present findings suggest that clinicians and researchers who use the FMS as an injury estimation tool should consider not penalizing subtest scores based on pain, because FMS pain was largely unrelated to subsequent injury risk.

Little is known about general pain prevalence in junior Australian football players. Research within senior Australian football players indicates that general pain and soreness are experienced throughout the body by players throughout the competitive season.[18] This consistent, general pain most likely reflects some combination of the soreness associated with high training workload, the full body–contact nature of the sport, and chronic pain associated with past injuries. It is also likely that a similar degree of soreness is experienced during the preseason, which is associated with higher weekly training loads compared to those during the season.[32] Similar trends would be expected for junior Australian football and could have

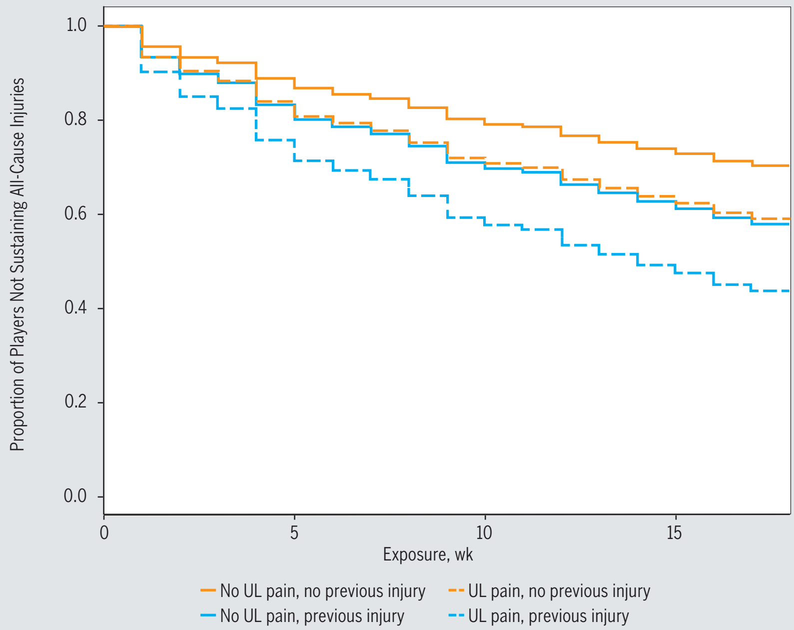

FIGURE 2. Survival plot identifying the proportion of players who did not sustain an all-cause injury, based on risk groups defined by previous injury status and the presence of UL pain during Functional Movement Screen testing. Abbreviation: UL, upper limb.

TABLE 2 Association Between Predictor Variables and Subsequent Noncontact Injury, Based on Univariable Analysis

Predictor Variable	Hazard Ratio[a]	Descriptor	*P* Value
Previous injury	1.52 (0.82, 2.81)	Small	.179
Pain	1.14 (0.61, 2.12)	Trivial	.682
Mild pain	0.99 (0.47, 2.07)	Trivial	.974
Moderate pain	1.28 (0.49, 3.37)	Trivial	.611
Severe pain	2.19 (0.52, 9.28)	Moderate	.286
Upper-limb pain	1.83 (0.84, 3.96)	Small	.126
Lower-limb pain	0.63 (0.22, 1.77)	Small	.380
Back pain	1.15 (0.58, 2.30)	Trivial	.688
CS-traditional[b]: score, ≤14	1.05 (0.56, 1.97)	Trivial	.878
CS-moderate[c]: score, ≤14	0.99 (0.54, 1.83)	Trivial	.974
CS-raw[d]: score, ≤14	1.10 (0.59, 2.04)	Trivial	.761

Abbreviation: CS, composite score.
[a]*Values in parentheses are 95% confidence interval.*
[b]*The sum of all subtest scores when painful subtests were scored zero.*
[c]*The sum of all subtest scores when painful subtests were scored zero, but only when pain was of moderate or greater severity.*
[d]*The sum of all subtest scores when no scoring adjustment was made to painful subtests.*

contributed to the high pain prevalence observed during late preseason FMS testing in the present study. Support for this interpretation is evident in the generally mild severity of pain reported by players in this study, which could be more consistent with training-related soreness, as opposed to a precursor and early warning sign of future injury. Additionally, playing hurt is often considered an indicator of greater mental toughness, which Australian football players and coaches value highly.[10] This belief is likely to contribute to a high incidence of untreated pain among players and could also contribute to the high prevalence of FMS pain.

The majority of pain during FMS testing was experienced in the back during the deep squat, trunk stability push-up, and press-up clearing tests. Some of this pain may reflect transient training-related soreness, but the longer-term ramifications of this back pain warrant further investigation. The high occurrence of back pain in players who are considered injury free may reflect players being more able to train and play matches with back pain compared to pain in the upper and lower limbs (ie, less conservative management). If correct, a large number of back-pain episodes would not be detected by conventional Australian football injury surveillance programs, which typically rely on missed training and matches to define injury occurrence.[35] Back injuries have not been a common injury detected by previous junior Australian football injury surveillance studies.[22,35] This has likely perpetuated a lack of knowledge about back pain in Australian football. The feasibility and efficacy of back-health programs among junior Australian football players should be explored, given the potential association of back pain with long-term disability and financial burden.[19]

Upper-limb pain during the FMS was less common than back pain but was associated with a small increase in subsequent injury risk when considered in isolation and a moderate increase in risk when combined with a previous injury. Upper-limb pain was typically experienced during the shoulder mobility and accompanying shoulder impingement clearing tests. Pain during these tests appears to be a slightly more useful finding for estimating injury risk compared to pain resulting from other FMS subtests, which was typically experienced in the lower limb or back. However, the associated HR was small when considered in isolation and unlikely to be clinically meaningful. Additionally, upper-limb FMS pain was a more specific than sensitive finding for injury risk estimation, similar to previous research involving other FMS variables that have demonstrated poor sensitivity.[11]

The null relationship between FMS composite score and subsequent injury risk in the present study is similar to nearly all previous FMS research in junior athletes. Null findings have been reported in junior Australian football,[7] soccer,[34] ice hockey,[3,12] cricket,[25] and mixed sport cohorts,[4] with only junior baseball athletes demonstrating a significant moderate relationship between low composite score and subsequent injury risk.[23] In comparison, most studies reporting strong FMS-and-injury relationships have involved senior athletes.[13,17,21] This apparent discrepancy could be partly explained by the lower FMS composite score typically observed in younger and developing athletes,[31] leading to more false-positive scores below the scoring threshold of 14 or less. In the present study, modifying the pain-scoring approach so that less strict scoring penalties were used for painful subtests resulted in higher FMS composite scores (ie, fewer test positives), but the relationship with injury remained nonsignificant.

Previous movement screening research has suggested that the FMS may be more relevant to noncontact injuries, which are theoretically more predictable than contact injuries, as the latter often result from largely uncontrollable factors such as contact with another player.[34] The present study suggests that this is not the case within junior Australian football. However, findings related to noncontact injuries in this study should be interpreted with some caution, due to injury mechanism information being unavailable for 36% of injured players.

This study has important limitations that should be considered when interpreting the overall findings. First, it is difficult to differentiate between clinically meaningful pain and the transient pain and soreness that are associated with training and competition. Our study attempted to do this by considering pain severity, which we expected to be greater when pain was clinically relevant. However, pain severity was not related to injury, and it is possible that more sophisticated methods are required to truly determine clinically meaningful pain for the purpose of injury prevention strategies. Second, there were 73 (17%) players who had observations from their junior year of under-18 competition excluded in favor of their second, more senior year, due to the requirement for independent observations in the Cox proportional hazard regression analysis. There was no intervention between the first and second season, and any learning effects from the first testing were expected to have diminished or disappeared during the 12-month interval between testing combines. It is possible that the relationship between pain during FMS testing and injury risk can change between years, but there were too few players with multiple observations to investigate this. Third, players from each club had likely completed different preseason training programs in the lead-up to the FMS testing, and this may have influenced the extent of pain and soreness reported. It is possible that testing players at the beginning of the preseason, when limited training has been completed, could be a more appropriate testing time than the middle of the preseason. Fourth, each club completed its own warm-up before FMS testing, and it is unclear whether this influenced FMS results. The FMS has acceptable reliability,[28] but the reliability of the testers participating in this study is not known.

CONCLUSION

Junior Australian football players experience a high prevalence of pain during FMS testing, and this pain results in a lower overall composite score. However, the FMS composite score had no relationship with subsequent injury, regardless of how painful FMS subtests were scored. The majority of FMS pain was of mild severity and was not associated with subsequent injury risk. Only upper-limb pain demonstrated a small, significant association with subsequent injury, but this finding had limited diagnostic value. Back pain was more common than upper- and lower-limb pain, and the longer-term ramifications of this high prevalence of back pain should be explored.

KEY POINTS

FINDINGS: Pain during Functional Movement Screen (FMS) testing is common in junior Australian football players and has a notable effect on the FMS composite score. However, subsequent injury risk is minimally affected by this pain and the composite score, regardless of how painful FMS subtests are scored.
IMPLICATIONS: The FMS composite score and reporting of pain have limited efficacy as injury risk estimation tools in junior Australian football players.
CAUTION: Injury mechanism information was unavailable for 36% of injured players.

ACKNOWLEDGMENTS: *The authors would like to acknowledge the support of Brenton Phillips and Julian Farkas of the SANFL, all 8 clubs in the SANFL under-18 competition, and the Macquarie University Doctor of Physiotherapy students who helped with data entry.*

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Drs Fuller, Chalmers, and Milanese conceived the study. All authors were involved in data acquisition. Drs Fuller and Chalmers performed the data analysis. All authors contributed to interpretation of the results as well as drafting and revising the manuscript. All authors gave approval of the final version of the manuscript and agree to be accountable for all aspects of the work.
DATA SHARING: Data are available on request. Additional group summary data are available from the corresponding author for inclusion in future meta-analyses on related research topics. Individual participant data are not available, because sharing of individual data was not included in the conditions of ethical approval and participant consent.
PATIENT AND PUBLIC INVOLVEMENT: Feedback from the SANFL team managers and medical staff was used to inform the design of the player tracking and injury reporting system used in this study. No SANFL partners were involved in the data analysis, interpretation, and write-up of the study.

REFERENCES

1. Alemany JA, Bushman TT, Grier T, et al. Functional Movement Screen: pain versus composite score and injury risk. *J Sci Med Sport*. 2017;20 suppl 4:S40-S44. https://doi.org/10.1016/j.jsams.2017.08.001
2. Australian Bureau of Statistics. Football: four games, one name. Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4156.0.55.001Feature+Article1May%202009. Accessed March 29, 2019.
3. Avery M, Wattie N, Holmes M, Dogra S. Seasonal changes in functional fitness and neurocognitive assessments in youth ice-hockey players. *J Strength Cond Res*. 2018;32:3143-3152. https://doi.org/10.1519/JSC.0000000000002399
4. Bardenett SM, Micca JJ, DeNoyelles JT, Miller SD, Jenk DT, Brooks GS. Functional Movement Screen normative values and validity in high school athletes: can the FMS™ be used as a predictor of injury? *Int J Sports Phys Ther*. 2015;10:303-308.
5. Bonazza NA, Smuin D, Onks CA, Silvis ML, Dhawan A. Reliability, validity, and injury predictive value of the Functional Movement Screen: a systematic review and meta-analysis. *Am J Sports Med*. 2017;45:725-732. https://doi.org/10.1177/0363546516641937
6. Bushman TT, Grier TL, Canham-Chervak MC, Anderson MK, North WJ, Jones BH. Pain on Functional Movement Screen tests and injury risk. *J Strength Cond Res*. 2015;29 suppl 11:S65-S70. https://doi.org/10.1519/JSC.0000000000001040
7. Chalmers S, Fuller JT, Debenedictis TA, et al. Asymmetry during preseason Functional Movement Screen testing is associated with injury during a junior Australian football season. *J Sci Med Sport*. 2017;20:653-657. https://doi.org/10.1016/j.jsams.2016.12.076
8. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function - part 1. *Int J Sports Phys Ther*. 2014;9:396-409.
9. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function-part 2. *Int J Sports Phys Ther*. 2014;9:549-563.
10. Coulter TJ, Mallett CJ, Singer JA. A subculture of mental toughness in an Australian Football League club. *Psychol Sport Exerc*. 2016;22:98-113. https://doi.org/10.1016/j.psychsport.2015.06.007
11. Dorrel BS, Long T, Shaffer S, Myer GD. Evaluation of the Functional Movement Screen as an injury prediction tool among active adult populations: a systematic review and meta-analysis. *Sports Health*. 2015;7:532-537. https://doi.org/10.1177/1941738115607445
12. Dossa K, Cashman G, Howitt S, West B, Murray N. Can injury in major junior hockey players be predicted by a pre-season Functional Movement Screen – a prospective cohort study. *J Can Chiropr Assoc*. 2014;58:421-427.
13. Duke SR, Martin SE, Gaul CA. Preseason Functional Movement Screen predicts risk of time-loss injury in experienced male rugby union athletes. *J Strength Cond Res*. 2017;31:2740-2747. https://doi.org/10.1519/JSC.0000000000001838
14. Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport*. 2006;9:3-9; discussion 10. https://doi.org/10.1016/j.jsams.2006.02.009
15. Fuller JT, Chalmers S, Debenedictis TA, et al. High prevalence of dysfunctional, asymmetrical, and painful movement in elite junior Australian Football players assessed using the Functional Movement Screen. *J Sci Med Sport*. 2017;20:134-138. https://doi.org/10.1016/j.jsams.2016.05.003
16. Gabbe BJ, Finch CF, Bennell KL, Wajswelner H. How valid is a self reported 12 month sports injury history? *Br J Sports Med*. 2003;37:545-547. https://doi.org/10.1136/bjsm.37.6.545
17. Garrison M, Westrick R, Johnson MR, Benenson J. Association between the Functional Movement Screen and injury development in college athletes. *Int J Sports Phys Ther*. 2015;10:21-28.
18. Gastin PB, Meyer D, Robinson D. Perceptions of wellness to monitor adaptive responses to training and competition in elite Australian football. *J Strength Cond Res*. 2013;27:2518-2526. https://doi.org/10.1519/JSC.0b013e31827fd600
19. Hurwitz EL, Randhawa K, Yu H, Côté P, Haldeman S. The Global Spine Care Initiative: a summary of the global burden of low back and neck pain studies. *Eur Spine J*. 2018;27:796-801. https://doi.org/10.1007/s00586-017-5432-9
20. Jensen MP, Tomé-Pires C, de la Vega R, Galán S, Solé E, Miró J. What determines whether a pain is rated as mild, moderate, or severe? The

importance of pain beliefs and pain interference. *Clin J Pain*. 2017;33:414-421. https://doi.org/10.1097/AJP.0000000000000429

21. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason Functional Movement Screen? *N Am J Sports Phys Ther*. 2007;2:147-158.

22. Lathlean TJH, Gastin PB, Newstead SV, Finch CF. The incidence, prevalence, severity, mechanism and body region of injury in elite junior Australian football players: a prospective cohort study over one season. *J Sci Med Sport*. 2018;21:1013-1018. https://doi.org/10.1016/j.jsams.2018.03.002

23. Lee CL, Hsu MC, Chang WD, et al. Functional movement screen comparison between the preparative period and competitive period in high school baseball players. *J Exerc Sci Fit*. 2018;16:68-72.

24. Marques VB, Medeiros TM, de Souza Stigger F, Nakamura FY, Baroni BM. The Functional Movement Screen (FMS™) in elite young soccer players between 14 and 20 years: composite score, individual-test scores and asymmetries. *Int J Sports Phys Ther*. 2017;12:977-985.

25. Martin C, Olivier B, Benjamin N. The Functional Movement Screen in the prediction of injury in adolescent cricket pace bowlers: an observational study. *J Sport Rehabil*. 2017;26:386-395. https://doi.org/10.1123/jsr.2016-0073

26. McCunn R, aus der Fünten K, Fullagar HH, McKeown I, Meyer T. Reliability and association with injury of movement screens: a critical review. *Sports Med*. 2016;46:763-781. https://doi.org/10.1007/s40279-015-0453-1

27. Moore E, Chalmers S, Milanese S, Fuller JT. Factors influencing the relationship between the Functional Movement Screen and injury risk in sporting populations: a systematic review and meta-analysis. *Sports Med*. 2019;49:1449-1463. https://doi.org/10.1007/s40279-019-01126-5

28. Moran RW, Schneiders AG, Major KM, Sullivan SJ. How reliable are Functional Movement Screening scores? A systematic review of rater reliability. *Br J Sports Med*. 2016;50:527-536. https://doi.org/10.1136/bjsports-2015-094913

29. Moran RW, Schneiders AG, Mason J, Sullivan SJ. Do Functional Movement Screen (FMS) composite scores predict subsequent injury? A systematic review with meta-analysis. *Br J Sports Med*. 2017;51:1661-1669. https://doi.org/10.1136/bjsports-2016-096938

30. Orchard JW, Seward H, Orchard JJ. Results of 2 decades of injury surveillance and public release of data in the Australian Football League. *Am J Sports Med*. 2013;41:734-741. https://doi.org/10.1177/0363546513476270

31. Portas MD, Parkin G, Roberts J, Batterham AM. Maturational effect on Functional Movement Screen™ score in adolescent soccer players. *J Sci Med Sport*. 2016;19:854-858. https://doi.org/10.1016/j.jsams.2015.12.001

32. Rogalski B, Dawson B, Heasman J, Gabbett TJ. Training and game loads and injury risk in elite Australian footballers. *J Sci Med Sport*. 2013;16:499-503. https://doi.org/10.1016/j.jsams.2012.12.004

33. Romiti M, Finch CF, Gabbe B. A prospective cohort study of the incidence of injuries among junior Australian football players: evidence for an effect of playing-age level. *Br J Sports Med*. 2008;42:441-446. https://doi.org/10.1136/bjsm.2007.042721

34. Rusling C, Edwards KL, Bhattacharya A, et al. The Functional Movement Screening tool does not predict injury in football. *Prog Orthop Sci*. 2015;1:41-46. https://doi.org/10.5455/pos.20150803113054

35. Scase E, Magarey ME, Chalmers S, Heynen M, Petkov J, Bailey S. The epidemiology of injury for an elite junior Australian Football cohort. *J Sci Med Sport*. 2012;15:207-212. https://doi.org/10.1016/j.jsams.2011.12.002

[VIEWPOINT]

ERIC J. HEGEDUS, DPT, PhD, OCS[1] • LORI A. MICHENER, PT, ATC, PhD, FAPTA[2] • AMEE L. SEITZ, DPT, PhD, OCS[3]

Three Key Findings When Diagnosing Shoulder Multidirectional Instability: Patient Report of Instability, Hypermobility, and Specific Shoulder Tests

J Orthop Sports Phys Ther 2020;50(2):52-54. doi:10.2519/jospt.2020.0602

Sonya is an 18-year-old outside hitter on her high school volleyball team. She also plays on 2 travel teams and has done so for the past 5 years. Volleyball is now her year-round sport. Sonya presents to you complaining of recent-onset intermittent pain in her shoulder and complains that her shoulder "feels loose." How do you approach diagnosing Sonya's shoulder problem?

Diagnosis: An Important Foundation to Providing High-Quality Care

In a differential diagnosis process, clinicians typically ask their patients about their history, symptoms, and perceptions, and perform a physical assessment. The examination information is combined with clinical experience to inform hypotheses about which structures are most likely associated with symptoms. With the physical assessment, the clinician aims to pinpoint the anatomical source of a patient's problem or to reproduce the symptoms by placing stress on the suspected culprit (eg, contraction, tension, or compression of tissue). For example, tests designed to detect a torn rotator cuff tendon have either an active or resisted component to discern pain or weakness implicating tendon pathology.

It is often difficult to be certain that a test accurately identifies the pathological source of symptoms. Sometimes, uncertainty is related to the close proximity of tissues affected by the same stress. For example, a shoulder impingement test compresses the rotator cuff tendons, subacromial bursa, and the labrum. Which is the culprit responsible for the patient's symptoms? Tissue damage may also have little contribution to the patient's symptoms when that patient presents with altered central pain perception (nociplastic pain) or dominant psychosocial factors.

How well a clinical examination test performs to rule in or rule out a pathology has been historically evaluated by comparing the results to a gold standard (eg, identifying a specific pathoanatomic lesion on imaging or with surgery). Clinical examination is relatively accurate for diagnosing an anterior cruciate ligament tear.[8] In contrast, diagnosing the source of low back pain symptoms may be more difficult due to the increasing prevalence of pathology with age, the

[1]High Point University, High Point, NC. [2]University of Southern California, Los Angeles, CA. [3]Northwestern University, Chicago, IL. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Eric J. Hegedus, 1 University Drive, High Point, NC 27265. E-mail: ehegedus@highpoint.edu

influence of psychosocial factors, and the poor correlation of imaging with signs and symptoms.

Sonya's Physical Assessment Findings

Sonya scores 7/9 on the Beighton score and tells you she has always been flexible. Active shoulder range-of-motion testing is unremarkable. Glenohumeral joint accessory motions are excessive in both shoulders. Resisted shoulder testing in cardinal planes is unremarkable. The apprehension test is positive for pain and apprehension, and the posterior apprehension test is positive for apprehension. During the posterior apprehension test, you note a distinctive outline of the humeral head at the posterior aspect of the joint. You stop the hyperabduction test at 110° of isolated glenohumeral abduction because Sonya reports tingling down her arm.

Diagnosing Multidirectional Instability: Clinical Pearls

Shoulder instability has varying mechanisms of injury (traumatic, atraumatic), direction (anterior, posterior, inferior, multiple directions), and severity (dislocation, subluxation). Classification systems based on clustering signs and symptoms have been developed to define subgroups of shoulder instability.[5] Despite this attempt at homogeneity, multidirectional instability (MDI) suffers from the same lack of diagnostic clarity as low back pain.

Because exercise-based nonsurgical care is the most frequently recommended treatment for MDI,[9] a clinical diagnosis of MDI is critical to direct treatment. Differential diagnosis can distinguish MDI from global hypermobility syndrome, which is important, as these 2 entities may require different treatment approaches and have different prognoses.

We outline 3 key areas to address when diagnosing MDI.

Patient Interview The absence of a patient report of a traumatic onset of symptoms is a valuable finding. The patient with MDI, often under the age of 35 years, may use phrases like "double-jointed" or "always been flexible." She may describe multiple episodes of subluxation, with a low level of irritability after the episodes. She may report pain or a feeling of instability typically at the end range of motion, which may occur in a single motion/position/plane (usually the most stressful or repetitive) or multiple motions/positions/planes. History of participating in overhead sports is relevant, because MDI may be related to repeated microtrauma.

Medical Comorbidities Consider screening for global hypermobility using the Beighton score.[1] The Beighton score is a series of 9 joint mobility maneuvers performed bilaterally and involving both the upper and lower extremities. A point is assigned for each positive maneuver, and, generally, a score of 5/9 is considered positive for benign hypermobility syndrome. *Benign* is an important word, as there is no evidence that the Beighton score helps diagnose anything more sinister.

We suggest that a higher Beighton score should, at least, bring into suspicion less benign hypermobility syndromes, including Marfan, Ehlers-Danlos, and Loeys-Dietz. These syndromes have diagnostic criteria, like the 2010 revised Ghent nosology for Marfan syndrome, which would heighten suspicion and require referral if met.[7]

Specific Shoulder Tests and Measures In addition to the factors discussed in the interview and medical history, there are some tests that likely have a greater ability to rule in MDI (**TABLE**). We say "likely" because these tests are also helpful in ruling in unidirectional instability, but are diagnostic of MDI.

The apprehension test has a positive likelihood ratio of 17.[4] The posterior apprehension test for posterior instability has a positive likelihood ratio of 19.[6] The hyperabduction test was originally described as an assessment of inferior instability.[3] Although the posterior apprehension test was validated in one high-bias study and the hyperabduction test has only been validated as a test for anterior instability, we suggest that a positive finding of apprehension on any 2 of these 3 tests, in the presence of a positive Beighton score, would enable a diagnosis of MDI.

The specific shoulder tests described in the **TABLE** do not rely on the clinician's

TABLE Suggested Tests to Rule in Multidirectional Instability

Test	Description	Positive Test	Negative Test
Apprehension	With the patient in a supine position and the arm in 90° of abduction, the examiner passively moves the arm into external rotation	Shoulder pain or a patient report of feeling unstable/apprehensive	Neither pain nor instability is reported when the end range of external rotation is reached
Posterior apprehension	With the patient in a supine position, the examiner applies a posterior force on the elbow while horizontally adducting and internally rotating the humerus	Patient report of feeling unstable/apprehensive	A lack of apprehension with the test
Hyperabduction	With the patient seated, the examiner stabilizes the clavicle and scapula with one hand, while abducting the patient's arm with the other hand	More than 105° of abduction indicates inferior glenohumeral ligament laxity The patient may report feeling unstable or apprehensive, or neurological or pain symptoms	105° or less of abduction

ability to perceive how much translation exists with manual assessment (eg, the sulcus sign)—a method fraught with reliability issues. We emphasize that a patient report of apprehension should characterize a positive test over a report of pain. While pain is often used as a positive sign, the use of pain in cases of instability likely decreases diagnostic accuracy.[2]

Diagnosing Sonya's Shoulder Problem

Based on history of overuse in a throwing-type motion in a young athlete, a report of her shoulder feeling "loose," a Beighton score greater than 5/9, positive apprehension tests, and a positive hyperabduction test (greater than 105°), we diagnosed Sonya as having MDI.

Tingling sensations with the hyperabduction test are not a positive finding, but we have observed this finding in clinical practice and suspect it is due to humeral-head encroachment on the brachial plexus. Likewise, an obvious appearance of the humeral head during the posterior apprehension test does not indicate a positive test but may indicate posterior capsule laxity. We would only consider referring Sonya for further genetic testing or diagnostic imaging after application of the diagnostic criteria for syndromes such as Ehlers-Danlos or Marfan.

SUMMARY

Arriving at a pathology-based diagnosis through the clinical examination is challenging. Literature addressing diagnostic accuracy of tests and measures is helpful for some pathologies. There are no validated clinical examination tests for shoulder MDI. Therefore, we propose using a combination of patient-reported and clinical examination findings.

Diagnosing MDI is important because a correct diagnosis can direct efficient treatment and enable differential diagnosis to rule out other pathologies. Distinguishing MDI from competing unidirectional instabilities and/or global hypermobility syndromes is important to the improvement of rehabilitation treatment approaches and patient outcomes. Our suggestions for diagnosing MDI may help practicing clinicians develop a heightened awareness of hypermobility and suspicion of syndromes, such as Marfan, that require referral.

We hope this Viewpoint fuels discussion and further research on this topic generally, and on our suggested testing regimen specifically. Classifying patients with MDI into a distinct subgroup may improve treatment and outcomes. We welcome further dialog on the diagnosis of shoulder MDI in patients with shoulder pain and dysfunction.

Key Points

- The clinical examination to diagnose shoulder MDI is based on expert opinion.
- The Beighton score should serve as a screening procedure for suspected shoulder MDI or suspected MDI as part of a larger hypermobility issue.
- To rule in MDI, use a positive finding on at least 2 of the following 3 tests: anterior apprehension, posterior apprehension, hyperabduction.
- Aim to reproduce the patient's feeling of apprehension when diagnosing MDI. A positive finding of pain instead of apprehension should be interpreted cautiously.
- Further research to determine whether MDI is a distinct subgroup necessitating specific treatment is warranted. ◉

REFERENCES

1. Beighton P, Horan F. Orthopaedic aspects of the Ehlers-Danlos syndrome. *J Bone Joint Surg Br*. 1969;51:444-453. https://doi.org/10.1302/0301-620X.51B3.444
2. Farber AJ, Castillo R, Clough M, Bahk M, McFarland EG. Clinical assessment of three common tests for traumatic anterior shoulder instability. *J Bone Joint Surg Am*. 2006;88:1467-1474. https://doi.org/10.2106/JBJS.E.00594
3. Gagey OJ, Gagey N. The hyperabduction test: an assessment of the laxity of the inferior glenohumeral ligament. *J Bone Joint Surg Br*. 2001;83:69-74. https://doi.org/10.1302/0301-620x.83b1.10628
4. Hegedus EJ, Goode AP, Cook CE, et al. Which physical examination tests provide clinicians with the most value when examining the shoulder? Update of a systematic review with meta-analysis of individual tests. *Br J Sports Med*. 2012;46:964-978. https://doi.org/10.1136/bjsports-2012-091066
5. Hettrich CM, Cronin KJ, Raynor MB, et al. Epidemiology of the Frequency, Etiology, Direction, and Severity (FEDS) system for classifying glenohumeral instability. *J Shoulder Elbow Surg*. 2019;28:95-101. https://doi.org/10.1016/j.jse.2018.08.014
6. Jia X, Petersen SA, Khosravi AH, Almareddi V, Pannirselvam V, McFarland EG. Examination of the shoulder: the past, the present, and the future. *J Bone Joint Surg Am*. 2009;91 suppl 6:10-18. https://doi.org/10.2106/JBJS.I.00534
7. Loeys BL, Dietz HC, Braverman AC, et al. The revised Ghent nosology for the Marfan syndrome. *J Med Genet*. 2010;47:476-485. https://doi.org/10.1136/jmg.2009.072785
8. van Eck CF, van den Bekerom MP, Fu FH, Poolman RW, Kerkhoffs GM. Methods to diagnose acute anterior cruciate ligament rupture: a meta-analysis of physical examinations with and without anaesthesia. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:1895-1903. https://doi.org/10.1007/s00167-012-2250-9
9. Warby SA, Pizzari T, Ford JJ, Hahne AJ, Watson L. The effect of exercise-based management for multidirectional instability of the glenohumeral joint: a systematic review. *J Shoulder Elbow Surg*. 2014;23:128-142. https://doi.org/10.1016/j.jse.2013.08.006

[RESEARCH REPORT]

JACK T. HICKEY, PhD, AEP[1] • **RYAN G. TIMMINS,** PhD[1] • **NIRAV MANIAR,** PhD[1]
EBONIE RIO, PT, PhD[2] • **PETER F. HICKEY,** PhD[3] • **CHRISTIAN A. PITCHER,** PhD, AEP[1]
MORGAN D. WILLIAMS, PhD[4] • **DAVID A. OPAR,** PhD[1]

Pain-Free Versus Pain-Threshold Rehabilitation Following Acute Hamstring Strain Injury: A Randomized Controlled Trial

SUPPLEMENTAL VIDEO ONLINE

Hamstring strain injuries (HSIs) remain the most prevalent cause of time lost from competition in a range of sports,[14,17,18,53] with associated performance[23] and financial consequences.[28] Deficits in function, such as reduced isometric knee flexor strength, exist acutely following HSI[4,44,58] and may increase reinjury risk if persistent at return-to-play (RTP) clearance.[16] Rehabilitation should aim to restore these deficits as quickly as possible following acute HSI and to return the injured athlete to his or her sport with minimal risk of reinjury.[26] However, even after completion of rehabilitation and RTP clearance, previously injured hamstrings may display eccentric strength[42,49,51,74] and biceps femoris long head (BFLH) fascicle length deficits,[73] which are both modifiable HSI risk factors.[11,52,71,79] Fyfe et al[22] hypothesized that a lack of eccentric loading and long-length exercise during early rehabilitation may contribute to residual deficits and the elevated risk of reinjury seen in previously injured hamstrings.[20,22,50]

OBJECTIVE: The primary aim was to compare time from acute hamstring strain injury (HSI) to return-to-play (RTP) clearance following a standardized rehabilitation protocol performed within either pain-free or pain-threshold limits. Secondary aims were to compare isometric knee flexor strength, biceps femoris long head (BFLH) fascicle length, fear of movement, and reinjury occurrence at the 6-month follow-up between pain-free and pain-threshold groups.

DESIGN: Randomized controlled trial.

METHODS: Forty-three men with acute HSIs were randomly allocated to a pain-free (n = 22) or pain-threshold (n = 21) rehabilitation group. Days from HSI to RTP clearance, isometric knee flexor strength, BFLH fascicle length, fear of movement, and reinjury occurrence at the 6-month follow-up were reported.

RESULTS: Median time from HSI to RTP clearance was 15 days (95% confidence interval [CI]: 13, 17) in the pain-free group and 17 days (95% CI: 11, 24) in the pain-threshold group, which was not significantly different ($P = .37$). Isometric knee flexor strength recovery at 90° of hip and 90° of knee flexion was greater in the pain-threshold group at RTP clearance by 15% (95% CI: 1%, 28%) and by 15% (95% CI: 1%, 29%) at 2-month follow-up, respectively. Improvement in BFLH fascicle length from baseline was 0.91 cm (95% CI: 0.34, 1.48) greater at 2-month follow-up in the pain-threshold group. Two reinjuries occurred in both the pain-free and pain-threshold groups between RTP clearance and the 6-month follow-up.

CONCLUSION: Pain-threshold rehabilitation did not accelerate RTP clearance, but resulted in greater recovery of isometric knee flexor strength and better maintenance of BFLH fascicle length, compared to pain-free rehabilitation. *J Orthop Sports Phys Ther 2020;50(2):91-103. Epub 28 Jun 2019. doi:10.2519/jospt.2020.8895*

KEY WORDS: *hamstring strain injury, muscle, pain, rehabilitation, return to play*

Eccentric loading and long-length exercises reduce HSI risk,[3,77,80] increase knee flexor strength and BFLH fascicle length in uninjured individuals,[1,10,54,55,72] and accelerate RTP time when emphasized during rehabilitation.[5,6] However, the introduction and progression of eccentric loading and long-length exercises may be delayed by the consistently implemented guideline to only perform and progress exercise in the absence of pain.[30] Delaying the start of exercise rehabilitation by 9

[1]School of Behavioural and Health Sciences, Australian Catholic University, Fitzroy, Australia. [2]La Trobe Sport and Exercise Medicine Research Centre, La Trobe University, Bundoora, Australia. [3]Division of Epigenetics and Development, Walter and Eliza Hall Institute of Medical Research, Parkville, Australia. [4]School of Health, Sport and Professional Practice, University of South Wales, Pontypridd, United Kingdom. Ethical approval for the current study was provided by the Australian Catholic University Human Research Committee (approval number 2015-307H). Dr Jack Hickey and Dr Maniar were recipients of research support funding through the Australian Government Research Training Program Scholarship for the duration of this study. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Jack T. Hickey, School of Behavioural and Health Sciences, Australian Catholic University, 115 Victoria Parade, Fitzroy, VIC 3065 Australia. E-mail: jack.hickey@acu.edu.au

days, compared to 2 days, after acute muscle injury prolongs time to return to play.[9] Therefore, delaying exposure to exercise rehabilitation due to pain may limit the ability to achieve beneficial adaptations and may prolong RTP clearance following acute HSI.

Pain avoidance during HSI rehabilitation is consistent with conventional guidelines for the treatment of acute muscle injuries.[37] However, these guidelines state that "the current treatment principles of injured skeletal muscle lack firm scientific basis,"[37] which were largely based on clinical experience or laboratory-based animal studies.[32-35,48] In chronic or postoperative musculoskeletal conditions, allowing exercise to be performed up to a pain threshold is safe[7,21,46,64,69,70] and may improve outcomes compared to remaining pain free.[65,67] Mild pain or discomfort is permitted during HSI rehabilitation[27,40,45]; however, the pain-threshold approach has never been directly compared to the conventional practice of pain avoidance while performing the same rehabilitation protocol.

Therefore, the primary aim of this study was to compare the number of days from acute HSI to RTP clearance following a standardized rehabilitation protocol performed within either pain-free or pain-threshold limits. The secondary aims were to investigate the impact of pain-free and pain-threshold rehabilitation protocols on isometric knee flexor strength, BFLH fascicle length, fear of movement, and reinjury occurrence at a 6-month follow-up. We hypothesized that pain-threshold rehabilitation would accelerate the time needed to achieve RTP clearance compared to pain-free rehabilitation.

METHODS

Study Design

This study was a single-center, efficacy, double-blind randomized controlled trial, designed and conducted at the Australian Catholic University in Melbourne, Australia in accordance with the Consolidated Standards of Reporting Trials guidelines. The Australian Catholic University Human Research Committee granted ethical approval (2015-307H), and the trial was registered with the Australian New Zealand Clinical Trials Registry (ACTRN12616000307404).

Participant Recruitment and Eligibility

Between February 2016 and May 2017, men and women aged 18 to 40 years and with a suspected HSI were invited to undergo an initial clinical assessment within 7 days of suffering acute-onset posterior thigh pain. Potential participants were recruited via advertisement of recruitment posters, and contact was made with sporting clubs and sports injury clinics around Melbourne, Australia. Informed written consent was provided by potential participants prior to undergoing a subjective interview and a series of clinical assessments to confirm the presence of acute HSI. Potential participants had to meet all predetermined eligibility criteria (**TABLE 1**)[45,81] to be included in the study.

Potential participants were excluded if they presented with signs and symptoms of other causes of posterior thigh pain (hamstring tendinopathy, referred lower back pain, etc), or warranted the opinion of a surgeon when complete muscle rupture was suspected. An independent physical therapist (E.R.) with 15 years of experience in sports injury clinical practice and research verified participant eligibility. Injuries were not confirmed via magnetic resonance imaging (MRI) or graded using subjective categorical systems; rather, variables collected during the initial clinical assessment were reported to indicate severity of injury on a more continuous and objective scale. This approach was taken because combinations of clinical assessments, such as between-leg deficits in strength, range of motion, and pain, correlate well with rehabilitation progression[83] and explain more of the variance in RTP clearance time following HSI than do MRI findings.[31,81]

Randomization and Blinding

Eligible participants were randomly allocated to either a pain-free or pain-threshold rehabilitation group after stratification for previous HSI and sex using a 4-block randomization approach. This was done by marking 4 separate folders: (1) male/previous HSI, (2) male/first-time HSI, (3) female/previous HSI, and (4) female/first-time HSI. Each of these folders contained 4 sealed and unmarked envelopes, which contained allocation to either the pain-free (2 envelopes) or pain-threshold (2 envelopes) group. The lead investigator (J.H.) randomly selected one of these sealed and unmarked envelopes and provided it to the participant to open, which revealed group allocation. These 4 envelopes were only replaced in their respective folders once the previous 4 had all been selected.

Participants allocated to the pain-free group were only permitted to perform and progress rehabilitation when, during exercise, they reported a complete absence of pain (0 on a 0-to-10 numeric rating scale [NRS]). In contrast, those in the pain-threshold group were permitted to perform and progress reha-

TABLE 1 Eligibility Criteria for Study Inclusion

- Men and women aged 18 to 40 years
- Acute-onset posterior thigh pain associated with clear injury mechanism (eg, high-speed running, kicking, etc) causing cessation of activity
- Present for initial clinical assessment within 7 days of suspected injury
- Pain on palpation of the injured muscle
- Pain localized to the site of injury during isometric knee flexor contraction

bilitation with a pain rating of 4 or less on the NRS during exercise. All participants were told how to report localized pain at the site of injury using the NRS, on which 0 represented "absolutely no pain" and 10 the "worst pain imaginable." Upon allocation, participants were informed only of the pain limits applicable to their respective group and then provided informed written consent prior to commencing rehabilitation. Participants were blinded to the presence of the alternative intervention to reduce the possibility of cross-group contamination. All objective outcome measures were collected by members of the research team (D.O., R.T., and N.M.) who were blinded to group allocation for the duration of the study.

Initial Subjective Interview

Injury details, demographic data, and relevant injury history were all ascertained from an initial subjective interview. The subjective interview was conducted by the lead investigator (J.H.), a health professional with 5 years' clinical experience in musculoskeletal injury assessment and rehabilitation. Upon completion of the subjective interview, participants completed the 17-item Tampa Scale of Kinesiophobia (TSK) to assess fear of movement.

Clinical Assessments

During each participant's initial visit to confirm acute HSI and prior to all subsequent rehabilitation sessions, a series of clinical assessments were conducted by members of the research team blinded to group allocation (D.O., R.T., and N.M.). First, ultrasound images were collected, and later analyzed offline by the same blinded and experienced investigator (R.T.), to ascertain BFLH architecture using previously described methodology with published reliability (intraclass correlation coefficient = 0.96-0.98; typical error, 2.1%-3.4%).[73]

The injured muscle was then palpated, with participants in a prone position, to determine injury location and pain. The assessor palpated along the length of the injured muscle to identify the location of peak palpation pain. Participants were asked to rate their pain on a 0-to-10 NRS, and the peak value was recorded. The distance from the ischial tuberosity to the site of peak palpation pain and the total craniocaudal length of palpable pain were also measured (centimeters).[4,83]

Hamstring range of motion was assessed via the passive straight leg raise[4,60] and active knee extension tests.[24,59] For both the passive straight leg raise and active knee extension, a digital inclinometer was placed on the anterior tibial border, just below the tibial tuberosity, to objectively measure the angle of hip flexion or knee extension, respectively, at the point of onset of localized pain or maximal tolerable stretch. Participants were asked to rate their pain on the 0-to-10 NRS if they experienced localized pain at the site of injury during either the passive straight leg raise or active knee extension. Three trials of the passive straight leg raise and active knee extension were performed on the uninjured (performed first) and injured legs, with the highest range-of-motion value and peak pain score recorded for each test.

Isometric knee flexor strength was assessed with the participant lying supine at 0°/0° and 90°/90° of hip/knee flexion, using an apparatus with published reliability (intraclass correlation coefficient = 0.87-0.91; typical error, 6.2%-8.1%).[29] In each position, the uninjured leg was tested prior to the injured leg, with 2 warm-up repetitions at 50%, then 75%, of perceived maximal effort followed by 3 maximal-effort isometric knee flexor contractions, with a minimum 30-second rest between trials. A standardized instruction, "Push your heel down into the strap, from complete rest without lifting up your heel, as fast and hard as you can, in 3, 2, 1, go," was given with strong verbal encouragement to ensure maximal effort. When performing contractions with the injured leg, the additional instruction of contracting "to an intensity that you feel comfortable with" was given. Participants were asked to report any pain localized to the site of injury on the NRS, with the peak pain score recorded in each position. For each day of testing, isometric knee flexor strength at both 0°/0° and 90°/90° was defined as the highest force output across 3 repetitions for each leg at each position. Isometric knee flexor strength of the injured leg was reported as a percentage relative to the strength of the participant's contralateral, uninjured leg at the initial clinical assessment,[83] to account for change with exposure to exercise performed by the uninjured leg during rehabilitation.

Rehabilitation Protocol

All participants performed a standardized rehabilitation protocol twice per week, consisting of hamstring-strengthening exercises and progressive running, with every session fully supervised by the lead investigator (J.H.). Participants were asked to rate pain at the site of injury on the NRS during each exercise or stage of progressive running. The only difference between the 2 groups was the amount of pain allowed during performance of the rehabilitation protocol, which determined whether an exercise would be performed and progressed on an individual basis. No pain-relieving strategies, such as ice, medication, or topical treatments, were provided to participants in either group during their supervised rehabilitation sessions. Pain-relieving strategies applied by participants outside of these sessions were not controlled. All participants were advised not to perform any additional rehabilitation exercises outside of their 2 supervised sessions per week. Participants were encouraged to gradually return to their regular team sports training throughout the rehabilitation period; however, they were advised to keep any running below the intensity that they had achieved during supervised progressive running at that time.

Hamstring-strengthening exercises involving either hip extension at moderate to long muscle lengths or knee flexion with eccentric bias were selected to target

BFLH fascicle length and eccentric knee flexor strength adaptations.[10,12] These exercises were bilateral and unilateral variations of a hamstring bridge, 45° hip extension, eccentric slider (**ONLINE VIDEOS**), and the Nordic hamstring exercise. During their first rehabilitation session, all participants attempted bilateral variations of the hamstring bridge, 45° hip extension, and eccentric slider. Participants were permitted to continue performing each exercise within their group's respective pain limits, with each exercise progressed on an individual basis using exercise-specific criteria (**FIGURE 1**).

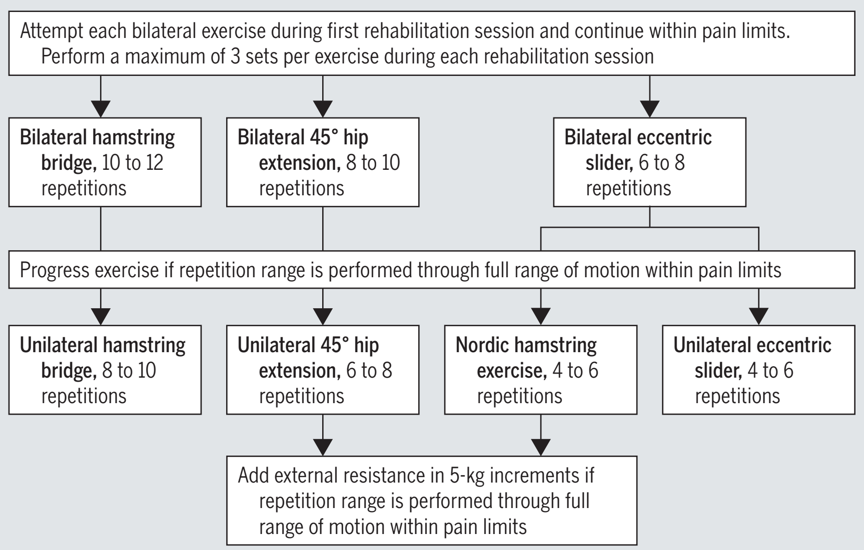

FIGURE 1. Exercise-specific progression criteria and prescribed repetition ranges for each exercise variation in the rehabilitation protocol.

Progressive running was based on the work of Silder et al[66] and included 9 stages of increasing intensity and hold distance and decreasing acceleration and deceleration distances over a total distance of 50 m (**TABLE 2**). Participants commenced progressive running once they could walk with normal gait within their group's pain limits. Jog, run, and sprint intensities were explained to participants as being upper limits of, respectively, 50%, 70%, and 100% of their perceived maximal running speed. Progression from one stage to the next was achieved once participants could perform 3 repetitions at the relevant upper-limit intensity within their group's pain limits. No more than 9 repetitions were permitted during each rehabilitation session.[66]

TABLE 2 INTENSITY AND DISTANCE OF THE 9-STAGE PROGRESSIVE RUNNING PROTOCOL[a]

Stage	Acceleration Phase	Hold Phase	Deceleration Phase
1	Walk 20 m	Jog 10 m	Walk 20 m
2	Walk 15 m	Jog 20 m	Walk 15 m
3	Walk 10 m	Jog 30 m	Walk 10 m
4	Jog 20 m	Run 10 m	Jog 20 m
5	Jog 15 m	Run 20 m	Jog 15 m
6	Jog 10 m	Run 30 m	Jog 10 m
7	Run 20 m	Sprint 10 m	Run 20 m
8	Run 15 m	Sprint 20 m	Run 15 m
9	Run 10 m	Sprint 30 m	Run 10 m

[a]*Walk is defined as regular gait, jog as less than 50% of perceived maximal running speed, run as less than 70% of perceived maximal running speed, and sprint as greater than 90% of perceived maximal running speed.*

TABLE 3 CRITERIA FOR RETURN-TO-PLAY CLEARANCE

- No pain on palpation of the injured muscle
- No pain during the active knee extension or passive straight leg raise test, with range of motion at 90% or greater of that of the contralateral, uninjured leg
- No pain during maximal-effort isometric knee flexor contraction at 0°/0° and 90°/90° of hip/knee flexion
- No pain or apprehension during sprinting at 100% of perceived maximal running intensity

Participants continued to perform this rehabilitation protocol twice per week until they met predetermined criteria for RTP clearance (**TABLE 3**), which were identical for all participants and based on the best available evidence.[2,78] Once RTP clearance criteria had been met, all participants were provided the same recommendation to complete at least 2 full training sessions prior to returning to competitive sport. However, the final decision to return to competition was left to the participant, coach, and medical/fitness staff at their respective sporting club to account for variation in sports, levels of competition, and the need for shared RTP decision making.[2,15,63] All participants were encouraged to continue with at least 1 hip extension and 1 eccentric knee flexion exercise once per week, although compliance was not enforced or monitored.

Follow-up

Participants were contacted at least once per month for a 6-month period following RTP clearance to monitor for reinjury. If participants suspected reinjury, they were instructed to contact the lead investigator (J.H.), and attempts were made to confirm the presence of an acute HSI via clinical assessment by a blinded investigator, based on the previously described study inclusion criteria. However, if this was not possible, then reinjury was confirmed via telephone conversation with the participant and communication with relevant contacts at the participant's sporting club, such as a team physical therapist. All suspected reinjuries were verified by an independent physical therapist (E.R.) blinded to group allocation.

Two months following RTP clearance, participants attended a follow-up assessment, except for those who had already suffered a reinjury. This assessment was conducted entirely by the same blinded assessor as the one during rehabilitation (D.O., R.T., or N.M.), with BFLH muscle architecture, isometric knee flexor strength, and score on the TSK assessed as previously described.

Outcome Measures

The primary outcome measure, time to RTP clearance, was the number of days from acute HSI to meeting all RTP clearance criteria. Secondary outcome measures were BFLH fascicle length, isometric knee flexor strength, fear of movement at the initial clinical assessment, RTP clearance, and 2-month follow-up, and the number of reinjuries in the 6 months following RTP clearance.

Statistical Analysis

An a priori sample-size calculation determined that 29 participants were required to achieve 80% power, accounting for a dropout rate of 20%. The sample-size calculation was based on an effect size of 1.2, comparing RTP time between HSI rehabilitation emphasizing lengthening and rehabilitation emphasizing conventional exercises.[5,6]

Statistical analysis was performed in R Version 3.4.3,[56] using custom-written code. Intention-to-treat analysis was used to investigate the treatment's effect on the number of days from acute HSI to RTP clearance and the number of reinjuries during the 6-month follow-up, using a Cox proportional hazard model. Time-to-RTP clearance and survival-from-reinjury curves were fit via the Kaplan-Meier method, using the "survival" package.[68] Participants who ceased rehabilitation prior to achieving RTP clearance criteria were censored from analysis at the time of their last completed session. Participants who did not complete the 6-month reinjury follow-up were censored at the last time point they were contacted.

Linear mixed models were used to investigate the effect of pain-free and pain-threshold rehabilitation (group) on BFLH fascicle length, isometric knee flexor strength, and fear of movement at RTP clearance and 2-month follow-up (time). Linear mixed models were fit via restricted maximum likelihood using the "lme4" package.[8] Group, time, and their interaction were treated as fixed effects, with participant modeled as a random

TABLE 4 Baseline Participant Characteristics and Results of Initial Clinical Assessment[a]

Variable	Pain-Free Group (n = 22)	Pain-Threshold Group (n = 21)
Age, y	27.4 ± 5.2	24.9 ± 5.3
Height, cm	180.1 ± 7.5	182.2 ± 8.2
Mass, kg	86.5 ± 13.5	86.3 ± 9.2
Sport, d/wk	3 ± 1	3 ± 1
Sport, n		
Australian football	18	14
Other	4	7
Prior hamstring strain injury, n		
Yes	16	14
No	6	7
Initial clinical assessment/start of rehabilitation, d from injury	3 ± 2	3 ± 1
Activity at time of injury, n		
Competition	14	15
Training	8	6
Injury location, n		
Lateral	18	15
Medial	4	6
Pain at time of injury (0-10 NRS)	5.7 ± 2.0	5.8 ± 1.5
Peak palpation pain (0-10 NRS)	3.1 ± 1.7	3.6 ± 2.0
Peak palpation pain distance from ischium, cm	20.2 ± 6.7	19.6 ± 6.4
Total length of palpable pain, cm	5.5 ± 3.4	5.8 ± 4.4
Passive straight leg raise pain (0-10 NRS)	2.5 ± 2.2	2.3 ± 2.4
Active knee extension pain (0-10 NRS)	3.3 ± 2.5	2.9 ± 2.7
Passive straight leg raise deficit, %[b]	89.9 ± 14.8	84.6 ± 18.2
Active knee extension deficit, %[b]	84.3 ± 20.8	71.9 ± 27.3
Isometric knee flexor pain at 0°/0° (0-10 NRS)[c]	3.7 ± 2.8	3.1 ± 2.6
Isometric knee flexor pain at 90°/90° (0-10 NRS)[c]	4.5 ± 2.6	4.8 ± 2.1
Isometric knee flexor strength at 0°/0°, %[b,c]	70.1 ± 26.9	66.8 ± 26.8
Isometric knee flexor strength at 90°/90°, %[b,c]	60.1 ± 25.2	60.1 ± 26.4

Abbreviation: NRS, numeric rating scale.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*Relative to the uninjured leg.*
[c]*Degrees of hip and knee flexion, respectively.*

effect to account for individual variability. Residuals were plotted and checked for approximate normality, and statistical significance was assessed using 95% confidence intervals (CIs).

RESULTS

Participants

All 51 potential participants screened for eligibility were men, as no women presented to the investigators with suspected HSIs, despite being eligible for inclusion. Of these 52 potential participants, 43 met inclusion criteria and were randomized to the pain-free group (n = 22) and the pain-threshold group (n = 21) (**TABLE 4**). All participants were compliant with the rehabilitation protocol, performing supervised sessions twice per week, with no adverse events (reinjuries) occurring prior to RTP clearance. One rehabilitation session was ceased as a precaution when a participant in the pain-threshold group reported pain of 7/10 during sprinting. However, this was not considered an adverse event, as predetermined criteria for reinjury were not met immediately after cessation of this session or prior to the subsequent rehabilitation session 2 days later. This participant continued to be fully compliant with pain-threshold rehabilitation from 2 days after this session until achieving RTP clearance criteria.

One participant in the pain-free group ceased rehabilitation 24 days following acute HSI, without meeting RTP clearance criteria, and was censored from further analysis at this time point. Data for all secondary outcome measures at 2-month follow-up were missing from 4 participants in the pain-free group and 3 participants in the pain-threshold group (**FIGURE 2**).

RTP Clearance

Criteria for RTP clearance were met by 21 of the 22 participants in the pain-free group in a median time of 15 days (95% CI: 13, 17), and by all 21 participants in the pain-threshold group in a median time of 17 days (95% CI: 11, 24) (**FIGURE 3A**). The hazard ratio for time taken to achieve RTP clearance in the pain-threshold group was 0.75 (95% CI: 0.40, 1.40) relative to the pain-free group, which was not significantly different (*P* = .37; score test of treatment effect in the Cox proportional hazard model) (**FIGURE 3B**).

BFLH Fascicle Length

Data from the initial clinical assessment of the BFLH were missing for 1 participant in the pain-free group and 1 participant in the pain-threshold group, due to the assessor for this measure (R.T.) not being available at this time point. From initial clinical assessment to RTP clearance, BFLH fascicle length significantly improved by an average of 1.70 cm (95% CI: 1.33, 2.08) in the pain-free group (**FIGURE 4A**) and 1.95 cm (95% CI: 1.41, 2.48) in the pain-threshold group (**FIGURE 4B**), with no significant difference between the 2 groups (95% CI: –0.29, 0.78). Despite a slight reduction in the 2 months following RTP clearance, BFLH fascicle length was still significantly greater than at the initial clinical assessment, by an average of 0.56 cm (95% CI: 0.16, 0.97) in the pain-free group and 1.47 cm (95% CI: 0.90, 2.04) in the pain-threshold group. The difference in BFLH fascicle length from the initial clinical assessment to 2-month follow-up was significantly greater in the pain-threshold group than in the pain-free group, by an average of 0.91 cm (95% CI: 0.34, 1.48).

Isometric Knee Flexor Strength

From initial clinical assessment to RTP clearance, significant improvements in isometric knee flexor strength were observed at 0°/0°, by an average of 32% (95% CI: 22%, 41%) in the pain-free group (**FIGURE 5A**) and 39% (95% CI: 26%, 52%) in the

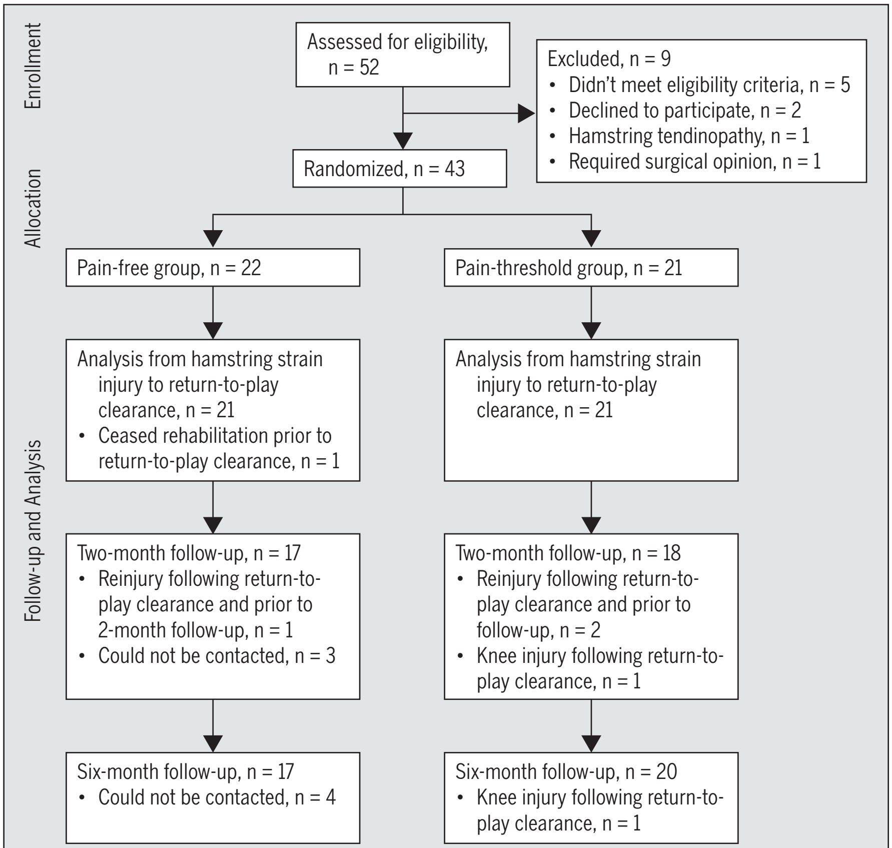

FIGURE 2. CONSORT diagram showing participant flow through the study, from enrollment to allocation, follow-up, and analysis.

pain-threshold group (**FIGURE 5B**), with no difference between groups (95% CI: –6%, 20%). Isometric knee flexor strength at 0°/0° remained significantly greater than at the initial clinical assessment in both groups 2 months following RTP clearance, with no significant difference between groups (95% CI: –6%, 22%).

Isometric knee flexor strength at 90°/90° improved significantly, by an average of 35% (95% CI: 26%, 44%) in the pain-free group (**FIGURE 5C**) and 49% (95% CI: 36%, 63%) in the pain-threshold group (**FIGURE 5D**), from initial clinical assessment to RTP clearance. This improvement was significantly greater, by an average of 15% (95% CI: 1%, 28%), in the pain-threshold group. Two months following RTP clearance, improvement in isometric knee flexor strength at 90°/90° from the initial clinical assessment remained significantly greater, by an average of 15% (95% CI: 1%, 29%), in the pain-threshold group.

Fear of Movement

Fear-of-movement data for 1 participant in the pain-threshold group at RTP clearance was missing, as the participant failed to complete the TSK at this time-point. According to the TSK, out of a maximum score of 68 points, fear of movement significantly reduced by an average of –7 points (95% CI: –5, –9) in the pain-free group (**FIGURE 6A**) and –8 points (95% CI: –5, –11) in the pain-threshold group (**FIGURE 6B**) from initial clinical assessment to RTP clearance. Between-group differences in reduction of fear of movement of –1 point (95% CI: –4, 2) at RTP clearance and –4 points (95% CI: –6, 0) at 2-month follow-up, compared to the initial clinical assessment, were nonsignificant.

Six-Month Reinjury Follow-up

All but 5 participants provided data at the 6-month follow-up assessment, 4 in the pain-free group who could not be contacted and 1 in the pain-threshold group who suffered an unrelated knee injury after RTP clearance. Two participants in the pain-free group suffered reinjuries 50 and 67 days after RTP clearance at 13 and 26 days, respectively, after the first HSI. Two participants in the pain-threshold group suffered reinjuries 8 and 17 days after RTP clearance at 6 and 11 days, respectively, after the first HSI (**FIGURE 7**). The hazard ratio for reinjury in the pain-threshold group was 1.05 (95% CI: 0.14, 7.47) relative to the pain-free group, which was not significantly different (P = 1.0; score test of treatment effect in the Cox proportional hazard model).

DISCUSSION

THE MAIN FINDING OF THIS RANDOMized controlled trial is that, following acute HSI, RTP clearance was not accelerated by performing and progressing a standardized rehabilitation protocol using a pain-threshold compared to a pain-free rehabilitation protocol. Regardless of the pain-threshold or pain-free group allocation, all participants showed large improvements in BFLH fascicle length and isometric knee flexor strength, along with reduced fear of movement. However, the pain-threshold rehabilitation protocol did result in greater recovery of isometric knee flexor strength at 90°/90° of hip/knee flexion for both RTP clearance and the 2-month follow-up time points and more sustained improvements in BFLH fascicle length 2 months after RTP clearance compared to pain-free rehabilitation.

This is the first randomized controlled trial with outcomes that did not support the long-held belief that pain-free rehabilitation is best clinical practice following acute muscle injury,[19,36-39,41,43] which is largely driven by fear of symptom exacerbation and/or reinjury.[37] In the current study, there was only a single rehabilitation session ceased, as a precaution due to pain exacerbation with sprinting; how-

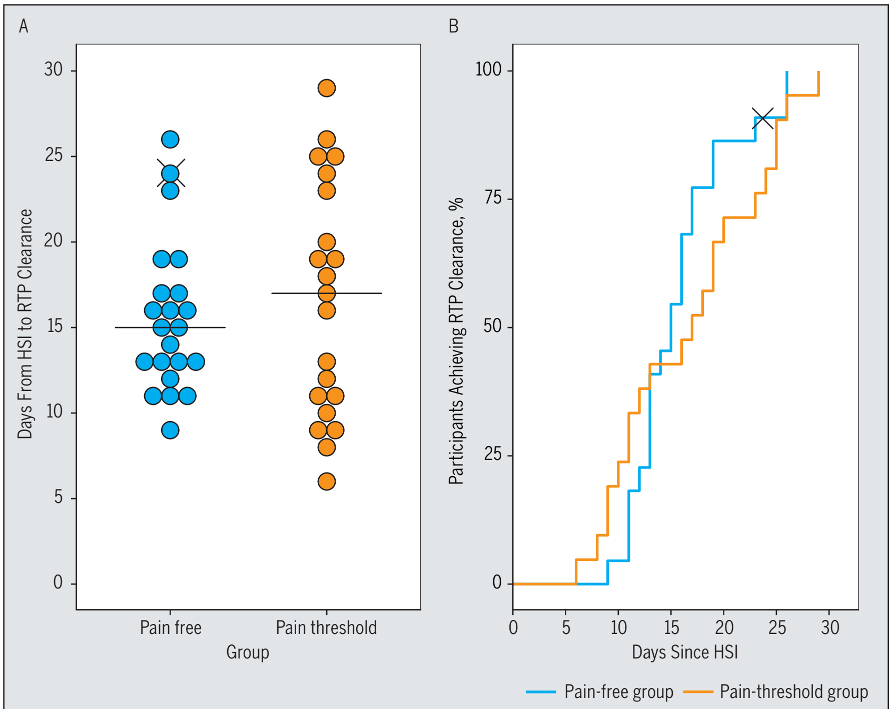

FIGURE 3. (A) Scatter plot of the number of days from HSI to RTP clearance for each individual participant within the pain-free and pain-threshold groups. The horizontal black lines represent the median RTP clearance time within each group. (B) Kaplan-Meier curves for the percentage of participants achieving RTP clearance within each group relative to the number of days since HSI. The "X" symbol in both (A) and (B) shows the amount of days from HSI to the last rehabilitation session completed by the 1 participant in the pain-free group who did not achieve RTP clearance. Abbreviations: HSI, hamstring strain injury; RTP, return to play.

ever, this was not a reinjury. Exposing participants to pain during rehabilitation did not induce fear, with both groups achieving significant reductions on the TSK from the initial clinical assessment to RTP clearance. Further, no adverse events occurred when exercise was permitted to continue and/or be progressed in the presence of pain rated up to 4/10 on the NRS in the pain-threshold group. The pain threshold of 4/10 or less was selected as a slightly more conservative version of the pain-monitoring model of 5/10 or less, previously implemented in patellofemoral joint pain and Achilles tendinopathy rehabilitation.[64,65,69] Selection of an appropriate pain threshold will always be somewhat of an arbitrary task, given the complex and subjective nature of pain perception.[47] Regardless of the specific pain threshold set, the current findings suggest that it is unnecessary to completely avoid pain during HSI rehabilitation.

Comparison of RTP clearance times in the current study to those previously reported in the HSI literature is difficult, due to inconsistent definitions of this outcome measure.[78] However, the RTP clearance times in the current study compare favorably to those in a previous study, which also reported time from HSI to meeting RTP clearance and reported a mean in excess of 21 days.[25] Perhaps of greater importance than RTP clearance time is that both groups achieved large improvements in isometric knee flexor strength and BFLH fascicle length within these relatively brief rehabilitation time frames.

Although both groups achieved large improvements in isometric knee flexor strength, recovery of between-leg deficits was greater in the pain-threshold group at 90°/90° of hip/knee flexion. Participants exposed to pain-threshold rehabilitation may have been more willing to contract to their maximal intensity if they saw pain as less of a barrier to exercise. However, between-group differences in isometric knee flexor strength were observed at RTP clearance and 2-month follow-up, at which all participants reported no pain. Therefore, allowing exercise to be performed and progressed up to a pain threshold appears to enhance recovery of isometric strength compared to avoiding pain during HSI rehabilitation.

The magnitudes of BFLH fascicle length improvement seen from the initial clinical assessment to RTP clearance in both groups were similar to those reported in uninjured males after 2 weeks of eccentric exercise.[55,72] In the current study, BFLH fascicle length improvements were relatively well maintained at 2-month follow-up, compared to the adaptation reversal seen after periods of detraining in uninjured males.[55,72] Lack of adaptation reversal may be explained by the advice given to all participants to continue with some form of eccentric loading at least once per week following RTP clearance. Although BFLH fascicle length improvements were better maintained at 2-month follow-up in the pain-threshold group, the mean ± SD increase from initial clinical assessment to RTP clearance of 1.82 ± 0.82 cm for all participants suggests adequate exposure to eccentric loading and long-length exercises in the current rehabilitation protocol, regardless of group allocation.

From the outset, eccentric loading and long-length exercises were introduced in the first rehabilitation session (average ± SD, 3 ± 2 days after HSI) and progressed individually, based on whether they could be performed through full range of motion for a prescribed repetition range within each group's pain limits. Askling et al[5,6] previously implemented similar exercise-specific progressions as part of the L-protocol, although rehabilitation did not commence until 5 days after HSI and progression was only allowed within strict pain-free limits. The L-protocol exercises recruit the hamstrings to a relatively low intensity[61] compared to the Nordic hamstring exercise[13] and eccentric sliding leg curl,[75] which were both implemented in the current rehabilitation protocol. It is typically recommended that progression to these exercises should be delayed during HSI rehabilitation until isometric knee flexor strength assessments are pain free[62] and/or within 10% of the uninjured leg.[45,76] However, we ob-

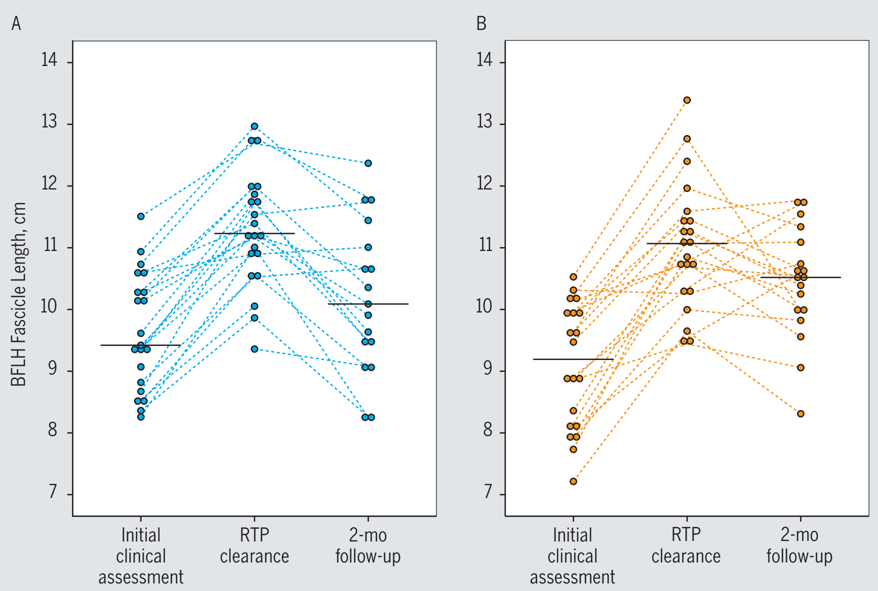

FIGURE 4. The BFLH fascicle length of the injured leg within (A) the pain-free group and (B) the pain-threshold group at the initial clinical assessment, RTP clearance, and 2-month follow-up. Each dot represents an individual participant, dotted lines indicate change over time, and the solid horizontal lines show the group medians. Abbreviations: BFLH, biceps femoris long head; RTP, return to play.

served that participants in the current study were often able to perform the Nordic hamstring exercise and the unilateral eccentric slider without pain, despite still reporting pain and/or demonstrating between-leg deficits greater than 10% during isometric knee flexor strength assessments. These findings suggest that eccentric loading can be progressed to a relatively high intensity by implementing exercise-specific criteria for progression, rather than delaying intervention by waiting for the alleviation of pain and/or between-leg deficits during isometric knee flexor strength assessments.

Interpretation of reinjury data is challenging due to the modest sample size and low number of reinjuries. Overall, the 4 reinjuries that occurred, as a percentage of the 37 participants compliant with 6-month follow-up, accounted for 11% of participants, which is comparable to recent HSI rehabilitation studies reporting rates of reinjury ranging from 4% to 30%.[25,45,58] Three of the 4 reinjuries in the current study occurred within 2 months of RTP clearance, which is consistent with data showing greater susceptibility to recurrence during this period.[25,82] Further, all 3 participants met RTP clearance within 2 weeks of their initial HSI. The 2 participants in the pain-threshold group who suffered reinjuries 8 and 17 days after RTP clearance at 6 and 11 days, respectively, following their initial HSI. These findings suggest a relationship between accelerated RTP clearance and elevated reinjury risk, along with potential inadequacies in the current RTP clearance criteria, which may need to better account for tissue healing time. Studies with larger numbers of participants and reinjuries are needed to shed more light on risk factors for HSI recurrence to better refine RTP criteria moving forward.

Our study used the revised Cochrane risk-of-bias tool for randomized trials to reduce risk of bias. Due to a concealed random-allocation sequence and blinding participants to the interventions, the risk of bias arising from the randomization process and deviations from the intended interventions was low. There may be bias related to the outcome of reinjury, as 20 of the 21 participants in the pain-threshold group completed 6-month follow-up, compared to 17 of the 22 participants in the pain-free group. However, risk of bias due to missing data and measurement of all other outcome measures was low, as the presence of missing data was reported and investigators were blinded to group allocation.

The current study is not without limitations. Confirmation of acute HSI was restricted to clinical assessment, as diagnostic tools such as MRI were not available. It is possible that although participants met inclusion criteria based on clinical assessment, some may have had a negative MRI result, which is associated with reduced RTP time.[57] However, many clinicians working with sports injuries are limited to confirming the presence

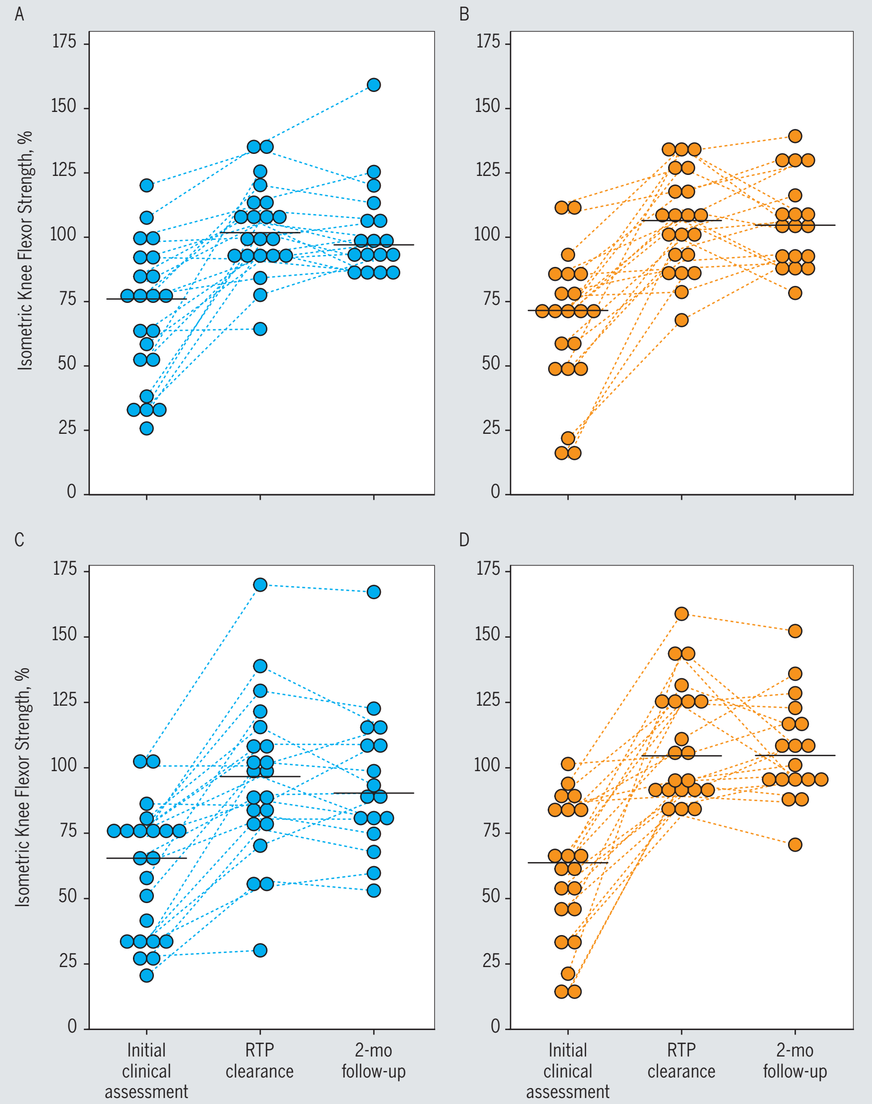

FIGURE 5. Isometric knee flexor strength of the injured leg at (A and B) 0°/0° and (C and D) 90°/90° of hip/knee flexion relative to the contralateral, uninjured leg (percent) within (A and C) the pain-free group and (B and D) the pain-threshold group at the initial clinical assessment, RTP clearance, and 2-month follow-up. Each dot represents an individual participant, dotted lines indicate change over time, and the solid horizontal lines show the group medians. Abbreviation: RTP, return to play.

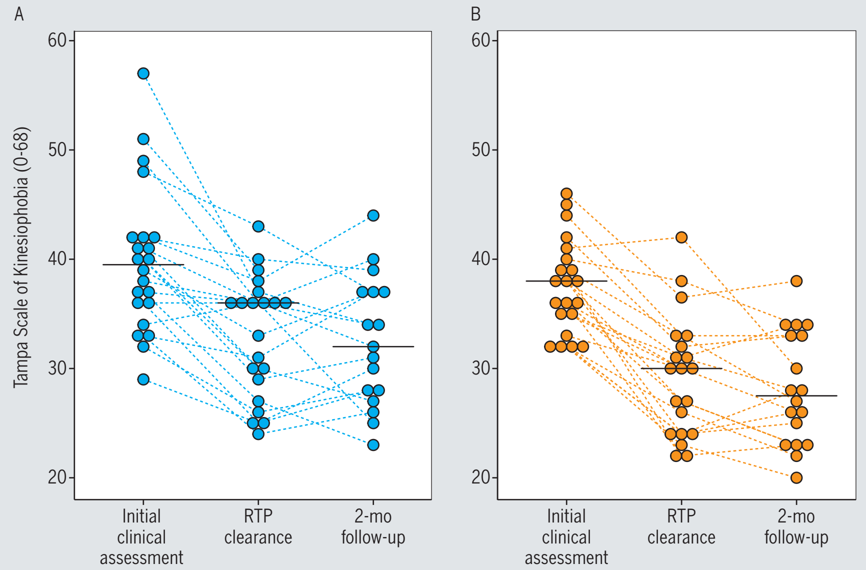

FIGURE 6. Fear of movement on the Tampa Scale of Kinesiophobia within (A) the pain-free group and (B) the pain-threshold group at the initial clinical assessment, RTP clearance, and 2-month follow-up. Each dot represents an individual participant, dotted lines indicate change over time, and the solid horizontal lines show the group medians. Abbreviation: RTP, return to play.

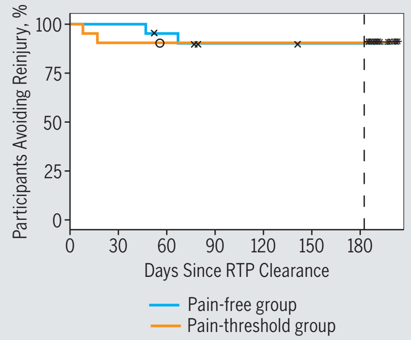

FIGURE 7. The percentage of participants avoiding reinjury in the 6 months following RTP clearance. The vertical dotted line indicates 182.5 days (6 months) from RTP clearance. The "X" symbol indicates the 4 participants in the pain-free group who were lost to follow-up and the last time point they were contactable. The "O" symbol represents the 1 participant in the pain-threshold group who suffered a knee injury during the 6-month follow-up period. The * symbols indicate the 15 participants in the pain-free group and the 18 participants in the pain-threshold group who completed 6-month follow-up without reinjury. Abbreviation: RTP, return to play.

of acute HSI using solely clinical assessments as described in this study, which enhances the ecological validity of the current findings. Return to full sporting activity was not reported, and it could be argued that the impact of pain-free and pain-threshold rehabilitation on complete recovery time is unclear. Time to RTP clearance using evidence-based criteria was chosen to reduce the influence of external factors on the primary outcome measure, such as pressure to return to different levels of sport participation, time of sports season, and team selection decisions from different coaches. Consequently, the primary outcome measure of time taken to achieve RTP clearance is more internally than externally valid.

CONCLUSION

Performing and progressing a standardized rehabilitation protocol up to a pain threshold did not accelerate RTP clearance compared to adhering to pain-free limits following acute HSI. However, pain-threshold rehabilitation did not cause any adverse events and resulted in greater recovery of isometric knee flexor strength and better maintenance of BFLH fascicle length improvements. Therefore, the conventional clinical practice of pain avoidance during HSI rehabilitation may not be necessary. ◉

KEY POINTS

FINDINGS: Pain-threshold rehabilitation did not accelerate return-to-play clearance compared to pain-free rehabilitation following acute hamstring strain injury, but did result in greater recovery of isometric knee flexor strength at 90°/90° of hip/knee flexion and better maintenance of biceps femoris long head fascicle length improvements.
IMPLICATIONS: The conventional practice of pain avoidance during hamstring strain injury rehabilitation may not be necessary, and emphasizing early progression of eccentric loading and long-length exercises appears to adequately address deficits in knee flexor strength and biceps femoris long head fascicle length.
CAUTION: The relatively small sample size and low number of reinjuries make it difficult to determine the impact of pain-free and pain-threshold rehabilitation on this outcome.

STUDY DETAILS

TRIAL REGISTRATION: Australian New Zealand Clinical Trials Registry (ACTRN12616000307404).
AUTHOR CONTRIBUTIONS: All authors met criteria for authorship based on the International Committee of Medical Journal Editors.
DATA SHARING: Deidentified data for outcomes reported in this manuscript are available on request from the corresponding author for research purposes.
PATIENT AND PUBLIC INVOLVEMENT: Participants and the public were not involved in the study design, conduct, interpretation, or translation of the research.

REFERENCES

1. Alonso-Fernandez D, Docampo-Blanco P, Martinez-Fernandez J. Changes in muscle architecture of biceps femoris induced by eccentric strength training with nordic hamstring exercise. *Scand J Med Sci Sports*. 2018;28:88-94. https://

doi.org/10.1111/sms.12877
2. Ardern CL, Glasgow P, Schneiders A, et al. 2016 consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. *Br J Sports Med*. 2016;50:853-864. https://doi.org/10.1136/bjsports-2016-096278
3. Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports*. 2003;13:244-250. https://doi.org/10.1034/j.1600-0838.2003.00312.x
4. Askling C, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. *Br J Sports Med*. 2006;40:40-44. https://doi.org/10.1136/bjsm.2005.018879
5. Askling CM, Tengvar M, Tarassova O, Thorstensson A. Acute hamstring injuries in Swedish elite sprinters and jumpers: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. *Br J Sports Med*. 2014;48:532-539. https://doi.org/10.1136/bjsports-2013-093214
6. Askling CM, Tengvar M, Thorstensson A. Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. *Br J Sports Med*. 2013;47:953-959. https://doi.org/10.1136/bjsports-2013-092165
7. Bandholm T, Thorborg K, Lunn TH, Kehlet H, Jakobsen TL. Knee pain during strength training shortly following fast-track total knee arthroplasty: a cross-sectional study. *PLoS One*. 2014;9:e91107. https://doi.org/10.1371/journal.pone.0091107
8. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. *J Stat Softw*. 2015;67:i01. https://doi.org/10.18637/jss.v067.i01
9. Bayer ML, Magnusson SP, Kjaer M. Early versus delayed rehabilitation after acute muscle injury [letter]. *N Engl J Med*. 2017;377:1300-1301. https://doi.org/10.1056/NEJMc1708134
10. Bourne MN, Duhig SJ, Timmins RG, et al. Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: implications for injury prevention. *Br J Sports Med*. 2017;51:469-477. https://doi.org/10.1136/bjsports-2016-096130
11. Bourne MN, Opar DA, Williams MD, Shield AJ. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: a prospective study. *Am J Sports Med*. 2015;43:2663-2670. https://doi.org/10.1177/0363546515599633
12. Bourne MN, Timmins RG, Opar DA, et al. An evidence-based framework for strengthening exercises to prevent hamstring injury. *Sports Med*. 2018;48:251-267. https://doi.org/10.1007/s40279-017-0796-x
13. Bourne MN, Williams MD, Opar DA, Al Najjar A, Kerr GK, Shield AJ. Impact of exercise selection on hamstring muscle activation. *Br J Sports Med*. 2017;51:1021-1028. https://doi.org/10.1136/bjsports-2015-095739
14. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *Am J Sports Med*. 2006;34:1297-1306. https://doi.org/10.1177/0363546505286022
15. Creighton DW, Shrier I, Shultz R, Meeuwisse WH, Matheson GO. Return-to-play in sport: a decision-based model. *Clin J Sport Med*. 2010;20:379-385. https://doi.org/10.1097/JSM.0b013e3181f3c0fe
16. De Vos RJ, Reurink G, Goudswaard GJ, Moen MH, Weir A, Tol JL. Clinical findings just after return to play predict hamstring re-injury, but baseline MRI findings do not. *Br J Sports Med*. 2014;48:1377-1384. https://doi.org/10.1136/bjsports-2014-093737
17. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med*. 2011;45:553-558. https://doi.org/10.1136/bjsm.2009.060582
18. Elliott MC, Zarins B, Powell JW, Kenyon CD. Hamstring muscle strains in professional football players: a 10-year review. *Am J Sports Med*. 2011;39:843-850. https://doi.org/10.1177/0363546510394647
19. Fernandes TL, Pedrinelli A, Hernandez AJ. Muscle injury – physiopathology, diagnosis, treatment and clinical presentation. *Rev Bras Ortop*. 2011;46:247-255. https://doi.org/10.1016/S2255-4971(15)30190-7
20. Freckleton G, Pizzari T. Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis. *Br J Sports Med*. 2013;47:351-358. https://doi.org/10.1136/bjsports-2011-090664
21. Frohm A, Saartok T, Halvorsen K, Renström P. Eccentric treatment for patellar tendinopathy: a prospective randomised short-term pilot study of two rehabilitation protocols. *Br J Sports Med*. 2007;41:e7. https://doi.org/10.1136/bjsm.2006.032599
22. Fyfe JJ, Opar DA, Williams MD, Shield AJ. The role of neuromuscular inhibition in hamstring strain injury recurrence. *J Electromyogr Kinesiol*. 2013;23:523-530. https://doi.org/10.1016/j.jelekin.2012.12.006
23. Hägglund M, Waldén M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med*. 2013;47:738-742. https://doi.org/10.1136/bjsports-2013-092215
24. Hamid MS, Ali MR, Yusof A. Interrater and intrarater reliability of the active knee extension (AKE) test among healthy adults. *J Phys Ther Sci*. 2013;25:957-961. https://doi.org/10.1589/jpts.25.957
25. Hamilton B, Tol JL, Almusa E, et al. Platelet-rich plasma does not enhance return to play in hamstring injuries: a randomised controlled trial. *Br J Sports Med*. 2015;49:943-950. https://doi.org/10.1136/bjsports-2015-094603
26. Heiderscheit BC, Sherry MA, Silder A, Chumanov ES, Thelen DG. Hamstring strain injuries: recommendations for diagnosis, rehabilitation, and injury prevention. *J Orthop Sports Phys Ther*. 2010;40:67-81. https://doi.org/10.2519/jospt.2010.3047
27. Herrington L. Patients with hamstring muscle strains returning to sport in less than 14 days: a case report of treatment used. *Phys Ther Sport*. 2000;1:137-138. https://doi.org/10.1054/ptsp.2000.0021
28. Hickey J, Shield AJ, Williams MD, Opar DA. The financial cost of hamstring strain injuries in the Australian Football League. *Br J Sports Med*. 2014;48:729-730. https://doi.org/10.1136/bjsports-2013-092884
29. Hickey JT, Hickey PF, Maniar N, et al. A novel apparatus to measure knee flexor strength during various hamstring exercises: a reliability and retrospective injury study. *J Orthop Sports Phys Ther*. 2018;48:72-80. https://doi.org/10.2519/jospt.2018.7634
30. Hickey JT, Timmins RG, Maniar N, Williams MD, Opar DA. Criteria for progressing rehabilitation and determining return-to-play clearance following hamstring strain injury: a systematic review. *Sports Med*. 2017;47:1375-1387. https://doi.org/10.1007/s40279-016-0667-x
31. Jacobsen P, Witvrouw E, Muxart P, Tol JL, Whiteley R. A combination of initial and follow-up physiotherapist examination predicts physician-determined time to return to play after hamstring injury, with no added value of MRI. *Br J Sports Med*. 2016;50:431-439. https://doi.org/10.1136/bjsports-2015-095073
32. Järvinen M. Healing of a crush injury in rat striated muscle. 2. A histological study of the effect of early mobilization and immobilization on the repair processes. *Acta Pathol Microbiol Scand A*. 1975;83:269-282. https://doi.org/10.1111/j.1699-0463.1975.tb01874.x
33. Järvinen M. Healing of a crush injury in rat striated muscle. 3. A micro-angiographical study of the effect of early mobilization and immobilization on capillary ingrowth. *Acta Pathol Microbiol Scand A*. 1976;84:85-94. https://doi.org/10.1111/j.1699-0463.1976.tb00114.x
34. Järvinen M. Healing of a crush injury in rat striated muscle. 4. Effect of early mobilization and immobilization on the tensile properties of gastrocnemius muscle. *Acta Chir Scand*. 1976;142:47-56.
35. Järvinen M, Sorvari T. Healing of a crush injury in rat striated muscle. 1. Description and testing of a new method of inducing a standard injury to the calf muscles. *Acta Pathol Microbiol Scand A*. 1975;83:259-265. https://doi.org/10.1111/j.1699-0463.1975.tb01383.x
36. Järvinen TA, Järvinen TL, Kääriäinen M, et al. Muscle injuries: optimising recovery. *Best Pract Res Clin Rheumatol*. 2007;21:317-331. https://doi.org/10.1016/j.berh.2006.12.004
37. Järvinen TA, Järvinen TL, Kääriäinen M, Kalimo H, Järvinen M. Muscle injuries: biology and

treatment. *Am J Sports Med*. 2005;33:745-764. https://doi.org/10.1177/0363546505274714
38. Järvinen TA, Kääriäinen M, Järvinen M, Kalimo H. Muscle strain injuries. *Curr Opin Rheumatol*. 2000;12:155-161. https://doi.org/10.1097/00002281-200003000-00010
39. Kannus P. Immobilization or early mobilization after an acute soft-tissue injury? *Phys Sportsmed*. 2000;28:55-63. https://doi.org/10.3810/psm.2000.03.775
40. Kilcoyne KG, Dickens JF, Keblish D, Rue JP, Chronister R. Outcome of grade I and II hamstring injuries in intercollegiate athletes: a novel rehabilitation protocol. *Sports Health*. 2011;3:528-533. https://doi.org/10.1177/1941738111422044
41. Kujala UM, Orava S, Järvinen M. Hamstring injuries. Current trends in treatment and prevention. *Sports Med*. 1997;23:397-404. https://doi.org/10.2165/00007256-199723060-00005
42. Lee MJ, Reid SL, Elliott BC, Lloyd DG. Running biomechanics and lower limb strength associated with prior hamstring injury. *Med Sci Sports Exerc*. 2009;41:1942-1951. https://doi.org/10.1249/MSS.0b013e3181a55200
43. Maffulli N, Oliva F, Frizziero A, et al. ISMuLT guidelines for muscle injuries. *Muscles Ligaments Tendons J*. 2013;3:241-249.
44. Maniar N, Shield AJ, Williams MD, Timmins RG, Opar DA. Hamstring strength and flexibility after hamstring strain injury: a systematic review and meta-analysis. *Br J Sports Med*. 2016;50:909-920. https://doi.org/10.1136/bjsports-2015-095311
45. Mendiguchia J, Martinez-Ruiz E, Edouard P, et al. A multifactorial, criteria-based progressive algorithm for hamstring injury treatment. *Med Sci Sports Exerc*. 2017;49:1482-1492. https://doi.org/10.1249/MSS.0000000000001241
46. Mikkelsen LR, Petersen AK, Mechlenburg I, Mikkelsen S, Søballe K, Bandholm T. Description of load progression and pain response during progressive resistance training early after total hip arthroplasty: secondary analyses from a randomized controlled trial. *Clin Rehabil*. 2017;31:11-22. https://doi.org/10.1177/0269215516628305
47. Moseley GL. Reconceptualising pain according to modern pain science. *Phys Ther Rev*. 2007;12:169-178. https://doi.org/10.1179/108331907X223010
48. Nikolaou PK, Macdonald BL, Glisson RR, Seaber AV, Garrett WE, Jr. Biomechanical and histological evaluation of muscle after controlled strain injury. *Am J Sports Med*. 1987;15:9-14. https://doi.org/10.1177/036354658701500102
49. Opar DA, Piatkowski T, Williams MD, Shield AJ. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. *J Orthop Sports Phys Ther*. 2013;43:636-640. https://doi.org/10.2519/jospt.2013.4837
50. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: factors that lead to injury and reinjury. *Sports Med*. 2012;42:209-226. https://doi.org/10.2165/11594800-000000000-00000
51. Opar DA, Williams MD, Timmins RG, Dear NM, Shield AJ. Knee flexor strength and bicep femoris electromyographical activity is lower in previously strained hamstrings. *J Electromyogr Kinesiol*. 2013;23:696-703. https://doi.org/10.1016/j.jelekin.2012.11.004
52. Opar DA, Williams MD, Timmins RG, Hickey J, Duhig SJ, Shield AJ. Eccentric hamstring strength and hamstring injury risk in Australian footballers. *Med Sci Sports Exerc*. 2015;47:857-865. https://doi.org/10.1249/MSS.0000000000000465
53. Orchard JW, Seward H, Orchard JJ. Results of 2 decades of injury surveillance and public release of data in the Australian Football League. *Am J Sports Med*. 2013;41:734-741. https://doi.org/10.1177/0363546513476270
54. Pollard CW, Opar DA, Williams MD, Bourne MN, Timmins RG. Razor hamstring curl and Nordic hamstring exercise architectural adaptations: impact of exercise selection and intensity. *Scand J Med Sci Sports*. 2019;29:706-715. https://doi.org/10.1111/sms.13381
55. Presland JD, Timmins RG, Bourne MN, Williams MD, Opar DA. The effect of Nordic hamstring exercise training volume on biceps femoris long head architectural adaptation. *Scand J Med Sci Sports*. 2018;28:1775-1783. https://doi.org/10.1111/sms.13085
56. R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing; 2014.
57. Reurink G, Brilman EG, de Vos RJ, et al. Magnetic resonance imaging in acute hamstring injury: can we provide a return to play prognosis? *Sports Med*. 2015;45:133-146. https://doi.org/10.1007/s40279-014-0243-1
58. Reurink G, Goudswaard GJ, Moen MH, et al. Rationale, secondary outcome scores and 1-year follow-up of a randomised trial of platelet-rich plasma injections in acute hamstring muscle injury: the Dutch Hamstring Injection Therapy study. *Br J Sports Med*. 2015;49:1206-1212. https://doi.org/10.1136/bjsports-2014-094250
59. Reurink G, Goudswaard GJ, Oomen HG, et al. Reliability of the active and passive knee extension test in acute hamstring injuries. *Am J Sports Med*. 2013;41:1757-1761. https://doi.org/10.1177/0363546513490650
60. Schneider-Kolsky ME, Hoving JL, Warren P, Connell DA. A comparison between clinical assessment and magnetic resonance imaging of acute hamstring injuries. *Am J Sports Med*. 2006;34:1008-1015. https://doi.org/10.1177/0363546505283835
61. Severini G, Holland D, Drumgoole A, Delahunt E, Ditroilo M. Kinematic and electromyographic analysis of the Askling L-Protocol for hamstring training. *Scand J Med Sci Sports*. 2018;28:2536-2546. https://doi.org/10.1111/sms.13288
62. Sherry MA, Johnston TS, Heiderscheit BC. Rehabilitation of acute hamstring strain injuries. *Clin Sports Med*. 2015;34:263-284. https://doi.org/10.1016/j.csm.2014.12.009
63. Shrier I. Strategic Assessment of Risk and Risk Tolerance (StARRT) framework for return-to-play decision-making. *Br J Sports Med*. 2015;49:1311-1315. https://doi.org/10.1136/bjsports-2014-094569
64. Silbernagel KG, Thomeé R, Eriksson BI, Karlsson J. Continued sports activity, using a pain-monitoring model, during rehabilitation in patients with Achilles tendinopathy: a randomized controlled study. *Am J Sports Med*. 2007;35:897-906. https://doi.org/10.1177/0363546506298279
65. Silbernagel KG, Thomeé R, Thomeé P, Karlsson J. Eccentric overload training for patients with chronic Achilles tendon pain – a randomised controlled study with reliability testing of the evaluation methods. *Scand J Med Sci Sports*. 2001;11:197-206. https://doi.org/10.1034/j.1600-0838.2001.110402.x
66. Silder A, Sherry MA, Sanfilippo J, Tuite MJ, Hetzel SJ, Heiderscheit BC. Clinical and morphological changes following 2 rehabilitation programs for acute hamstring strain injuries: a randomized clinical trial. *J Orthop Sports Phys Ther*. 2013;43:284-299. https://doi.org/10.2519/jospt.2013.4452
67. Smith BE, Hendrick P, Smith TO, et al. Should exercises be painful in the management of chronic musculoskeletal pain? A systematic review and meta-analysis. *Br J Sports Med*. 2017;51:1679-1687. https://doi.org/10.1136/bjsports-2016-097383
68. Therneau TM. survival: Survival Analysis. Available at: https://cran.r-project.org/web/packages/survival/index.html. Accessed January 2, 2020.
69. Thomeé R. A comprehensive treatment approach for patellofemoral pain syndrome in young women. *Phys Ther*. 1997;77:1690-1703. https://doi.org/10.1093/ptj/77.12.1690
70. Thorstensson CA, Roos EM, Petersson IF, Ekdahl C. Six-week high-intensity exercise program for middle-aged patients with knee osteoarthritis: a randomized controlled trial [ISRCTN20244858]. *BMC Musculoskelet Disord*. 2005;6:27. https://doi.org/10.1186/1471-2474-6-27
71. Timmins RG, Bourne MN, Shield AJ, Williams MD, Lorenzen C, Opar DA. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. *Br J Sports Med*. 2016;50:1524-1535. https://doi.org/10.1136/bjsports-2015-095362
72. Timmins RG, Ruddy JD, Presland J, et al. Architectural changes of the biceps femoris long head after concentric or eccentric training. *Med Sci Sports Exerc*. 2016;48:499-508. https://doi.org/10.1249/MSS.0000000000000795
73. Timmins RG, Shield AJ, Williams MD, Lorenzen C, Opar DA. Biceps femoris long head architecture: a reliability and retrospective injury study. *Med Sci Sports Exerc*. 2015;47:905-913. https://doi.org/10.1249/MSS.0000000000000507
74. Tol JL, Hamilton B, Eirale C, Muxart P, Jacobsen P, Whiteley R. At return to play following hamstring injury the majority of professional football players have residual isokinetic deficits. *Br J Sports Med*. 2014;48:1364-1369. https://doi.org/10.1136/

bjsports-2013-093016
75. Tsaklis P, Malliaropoulos N, Mendiguchia J, et al. Muscle and intensity based hamstring exercise classification in elite female track and field athletes: implications for exercise selection during rehabilitation. *Open Access J Sports Med*. 2015;6:209-217. https://doi.org/10.2147/OAJSM.S79189
76. Valle X, Tol JL, Hamilton B, et al. Hamstring muscle injuries, a rehabilitation protocol purpose. *Asian J Sports Med*. 2015;6:e25411.
77. van der Horst N, Smits DW, Petersen J, Goedhart EA, Backx FJ. The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: study protocol for a randomised controlled trial. *Inj Prev*. 2014;20:e8. https://doi.org/10.1136/injuryprev-2013-041092
78. van der Horst N, van de Hoef S, Reurink G, Huisstede B, Backx F. Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria. *Sports Med*. 2016;46:899-912. https://doi.org/10.1007/s40279-015-0468-7
79. van Dyk N, Bahr R, Whiteley R, et al. Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: a 4-year cohort study. *Am J Sports Med*. 2016;44:1789-1795. https://doi.org/10.1177/0363546516632526
80. van Dyk N, Behan FP, Whiteley R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. *Br J Sports Med*. 2019;53:1362-1370. https://doi.org/10.1136/bjsports-2018-100045
81. Wangensteen A, Almusa E, Boukarroum S, et al. MRI does not add value over and above patient history and clinical examination in predicting time to return to sport after acute hamstring injuries: a prospective cohort of 180 male athletes. *Br J Sports Med*. 2015;49:1579-1587. https://doi.org/10.1136/bjsports-2015-094892
82. Wangensteen A, Tol JL, Witvrouw E, et al. Hamstring reinjuries occur at the same location and early after return to sport: a descriptive study of MRI-confirmed reinjuries. *Am J Sports Med*. 2016;44:2112-2121. https://doi.org/10.1177/0363546516646086
83. Whiteley R, van Dyk N, Wangensteen A, Hansen C. Clinical implications from daily physiotherapy examination of 131 acute hamstring injuries and their association with running speed and rehabilitation progression. *Br J Sports Med*. 2018;52:303-310. https://doi.org/10.1136/bjsports-2017-097616

Introducing *JOSPT Cases*

CHRISTOPHER HUGHES, *PT, PhD, OCS, CSCS*
Editor: Education

R. BENJAMIN KEETON, *PT, DPT, MBA, OCS*
KRIS PORTER, *PT, DPT, OCS*
Associate Editors: Education

J Orthop Sports Phys Ther 2020;50(2):50-51. doi:10.2519/jospt.2020.0101

Evidence-based health care has 4 major components: evidence generation, evidence synthesis, evidence/knowledge transfer, and evidence utilization.[5] The *Journal of Orthopaedic & Sports Physical Therapy* (*JOSPT*) publishes quality systematic reviews, scientifically rigorous randomized controlled trials, and best-practice research organized in clinical practice guidelines. *JOSPT* has also published case reports, which, with editorials and expert opinion, form the base of the iconic hierarchy-of-evidence pyramid (**FIGURE**). Since 1979, *JOSPT* has published 214 case reports and 56 resident's case problems.

Case reports have educational value in their descriptions of practice. Though lacking controls, well-written cases reflect inquiry, problem solving, and clinical decision making from examination and diagnosis through treatment and outcomes. Clinicians can immediately relate to and apply these elements in practice.

In a 2019 JOSPT survey, readers asked for "clinically relevant, case-based educational tools." Their request highlights the need for more resources to help translate research findings into clinical practice, and also aligns with a top strategic goal for JOSPT in 2020-2021.

In response to these needs and to expand the educational value of case reports in clinical practice, we are pleased to introduce *JOSPT Cases*, a peer-reviewed, online quarterly journal that will launch in 2020.

FIGURE. The hierarchy of evidence. Modified under a Creative Commons license (https://creativecommons.org/licenses/by-nc-sa/3.0/) from https://uic.blackboard.com/courses/1/cont.library_tutorials.jamied.1/content/_4166951_1/dir_NursingResearchDesign.zip/index.html.

Creating Robust Case-Based Learning Tools

JOSPT Cases is being designed by the Editorial Board's Education team to expedite the integration of a growing body of knowledge directly into practice.[1-3,6,7] The new journal will provide a focused forum for case reports and deliver high value to readers. There will be new and innovative content to complement JOSPT's cache of "clinically relevant, case-based educational tools," which includes the organization's well-established Read for Credit continuing education program. Specifically, *JOSPT Cases* will have a web-based format that leverages technology to enhance the reader experience, with interactive multimedia, embedded quizzes, social media, and other features that static text cannot provide.

JOSPT Cases will also include patient narratives whenever possible. Patients play a key role in driving solutions to important clinical questions,[1] and we want to emphasize their perspectives in the cases we publish.

Opportunities for Clinician Authors

Case report writing has gained momentum in Doctor of Physical Therapy curricula, residency programs, and fellowship programs seeking reflective and scholarly activities for their learners.[4] *JOSPT Cases* creates an opportunity for clinicians at all levels of experience to become authors.

For those who wish to submit a case report but are new to case writing, the JOSPT Education team has created a template, described in detail in *JOSPT Cases*' instructions for authors (available at https://www.jospt.org/josptcases). This template can also be found at https://mc.manuscriptcentral.com/jospt (ScholarOne) and will guide new contributors through JOSPT's submission and review process, detailing what a case report should include (**TABLE**). We are receiving and reviewing submissions now.

TABLE	CASE REPORT STRUCTURE
Element	**Description**
Title	• Keep the case title clinical and straightforward
Abstract	• Summarize the case presentation and outcome in a maximum of 150 words. Emphasize what clinicians can learn from the case. Include a Key Words section with up to 6 key words immediately following the abstract
Background	• Why is this case important for rehabilitation clinicians? Introduce the key knowledge translation and clinical learning concepts that this case demonstrates
Case presentation	• Provide a concise account of the case, including relevant, diagnostically important patient medical/social/family history. Ensure that personal data provided are not identified unless consent is obtained. Chronological sequence provides logical structure
Differential diagnosis	• Decision tree used by author(s). Describe in detail how the final physical therapy diagnosis was determined. Describe relevant findings from subjective and objective examination. Present a clear rationale for the diagnosis
Treatment	• Detail all aspects of the care provided, pharmacological and nonpharmacological (eg, surgery, physical therapy, supportive care). Include parameters of physical therapy care when appropriate/relevant. Consider using multimedia, such as videos, to demonstrate care to learners in a more robust way
Outcome and follow-up	• Explain outcome measures/tools used to show results. If applicable, describe any short- and long-term follow-up provided
Discussion	• Describe mechanisms of pathology/injury, guidelines and their relevance, diagnostic pathways (using diagrams as appropriate), and the points of interest of the case • *Literature review*: concisely compare the case to the literature and briefly describe the literature search, including databases, medical subject headings, and years searched. Select only those articles strictly relevant to the reported case and its discussion. Include a brief review of similar published cases, if relevant • *Clinical practice guidelines*: summarize relevant clinical practice guidelines. Were exceptions to the guidelines required? Were the guidelines adopted, and, if so, how? • *Patient perspective*: provide the patient's perspective on the case in a short narrative format. Give the patient/next of kin the opportunity to comment on his or her experience dealing with both the condition and the care and outcome(s)
Learning points	• State in 3 to 5 bullet points what readers should remember about this case when seeing their own patients

JOSPT Cases will not charge an author fee. Online access will be provided to individuals and institutions by subscription. The new journal will also be available in print-on-demand format for readers who wish to purchase a hard-copy version.

By creating a case-based forum for clinically relevant discussion, while maintaining the scientific rigor that characterizes the flagship journal, *JOSPT*, we believe that *JOSPT Cases* will significantly improve the translation of research to practice in the field of rehabilitation. We encourage and welcome your feedback on this initiative. Comments may be sent to jospt@jospt.org. ◉

REFERENCES

1. Belton J, Hoens A, Scott A, Ardern CL. Patients as partners in research: it's the right thing to do. *J Orthop Sports Phys Ther*. 2019;49:623-626. https://doi.org/10.2519/jospt.2019.0106
2. CARE Group. CARE case report guidelines. Available at: https://www.care-statement.org/. Accessed November 28, 2019.
3. Fitzgerald GK. Focus and value added: the new case report. *Phys Ther*. 2007;87:494-495. https://doi.org/10.2522/ptj.2007.87.5.494
4. Florek AG, Dellavalle RP. Case reports in medical education: a platform for training medical students, residents, and fellows in scientific writing and critical thinking. *J Med Case Rep*. 2016;10:86. https://doi.org/10.1186/s13256-016-0851-5
5. Jordan Z, Munn Z, Aromataris E, Lockwood C. Now that we're here, where are we? The JBI approach to evidence-based healthcare 20 years on. *Int J Evid Based Healthc*. 2015;13:117-120. https://doi.org/10.1097/XEB.0000000000000053
6. McEwen I. *Writing Case Reports: A How-to Manual for Clinicians*. 3rd ed. Alexandria, VA: American Physical Therapy Association; 2009.
7. Rothstein JM. The case for case reports. *Phys Ther*. 1993;73:492-493. https://doi.org/10.1093/ptj/73.8.492