Preseason shoulder range of motion screening and in-season risk of shoulder and elbow injuries in overhead athletes: systematic review and meta-analysis

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ABSTRACT

Objective To characterise whether preseason screening of shoulder range of motion (ROM) is associated with the risk of shoulder and elbow injuries in overhead athletes.

Design Systematic review and meta-analysis.

Data sources Six electronic databases up to 22 September 2018.

Eligibility criteria Inclusion criteria were (1) overhead athletes from Olympic or college sports, (2) preseason measures of shoulder ROM, (3) tracked in-season injuries at the shoulder and elbow, and (4) prospective cohort design. Exclusion criteria were (1) included contact injuries, (2) lower extremity, spine and hand injuries, and (3) full report not published in English.

Results Fifteen studies were identified, and they included 3314 overhead athletes (baseball 74.6%, softball 3.1%, handball 16.1%, tennis 2.0%, volleyball 2.0% and swimming 2.2%). Female athletes were underrepresented (12% of the overall sample). Study quality ranged from 11 to 18 points on a modified Downs and Black checklist (maximum score 21, better quality). In one study, swimmers with low (<93°) or high (>100°) shoulder external rotation were at higher risk of injuries. Using data pooled from three studies of professional baseball pitchers, we showed in the meta-analysis that shoulder external rotation insufficiency (throwing arm <5° greater than the non-throwing arm) was associated with injury (odds ratio=1.90, 95% confidence interval 1.24 to 2.92, p<0.01).

Conclusion Preseason screening of shoulder external rotation ROM may identify professional baseball pitchers and swimmers at risk of injury. Shoulder ROM screening may not be effective to identify handball, softball, volleyball and tennis players at risk of injuries. The results of this systematic review and meta-analysis should be interpreted with caution due to the limited number of studies and their high degree of heterogeneity.

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INTRODUCTION

Overuse shoulder and elbow injuries are common across different overhead athletes regardless of age, sex and level of playing.14 Evaluating potential environmental-specific (extrinsic) and individual-specific (intrinsic) risk factors for shoulder and elbow injuries in overhead athletes is a research priority. Extrinsic risk factors include sport specialisation, training intensity, number of games per week, and number of pitches or throws per game and over a year.6–10 Extrinsic factors may contribute to overuse injuries due to repetitive load on the shoulder and elbow without adequate time to recover. Intrinsic non-modifiable risk factors include age, height, sex and previous injury.6–7 Impairments of joint range of motion (ROM) except when attributable to humeral torsion,8–10 strength10 and neuromuscular control10 are intrinsic modifiable risk factors because their effect may be modifiable through targeted injury prevention programmes.21

Changes or side-to-side differences of shoulder ROM result from the repetitive demands of overhead sport,22–24 but they may also be a risk factor for injury. In Keller’s systematic review, injured overhead athletes (baseball, handball and tennis) had deficits of shoulder internal rotation, external rotation and total rotation ROM.25 Limitations included studies with cross-sectional and retrospective designs, so it is impossible to determine whether the deficits in ROM were present before the injury or were an adaptation to the injury.16 Using prospective cohort studies, Bullock et al17 meta-analysis showed that high school baseball players who sustained an in-season shoulder and elbow injuries have less pre-season shoulder internal rotation (absolute value: 44°, side-to-side difference: 5°) and total rotation (absolute value 160°, side-to-side difference: 8°) ROM compared with players who did not sustain an injury during the season. However, the authors did not report the magnitude of risk in-season injuries with an odds or risk ratio for the players with the defined pre-season ROM values.17 Understanding the strength of the association between risk factors (preseason ROM) and outcomes (injury) is critical to evaluate the ability of preseason ROM to predict risk of injury in overhead athletes, and to design screening and prevention programmes.21

The purpose of this systematic review and meta-analysis was to summarise the available evidence, to evaluate the quality of research methods and to characterise the association of preseason shoulder ROM with future risk of shoulder and elbow injuries in prospective cohorts of overhead athletes. We hypothesised that preseason ROM measures of shoulder internal rotation, external rotation, horizontal adduction, shoulder flexion and total rotation have the potential to identify overhead athletes at risk of shoulder and elbow injuries.
METHODS
This review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.25 The review protocol was registered on PROSPERO.

Data source and search
The following databases were queried for existing evidence (from their inception to September 2018): MEDLINE, Scopus, Embase, Cochrane Library, Cumulative Index to Nursing and Allied Health Literature and SPORTdiscus (via Ebsco). A full-time librarian from the Norris Medical Library of the University of Southern California developed and conducted the search strategy for each database. The search strategies used to query MEDLINE and Cochrane Library are reported in online supplementary appendix A and were adapted for the other databases. Three senior authors with expertise in upper extremity injury in overhead athletes (ES, CAT and LAM) reviewed the list of the included studies to identify studies that were not found through the systematic search of the databases. Further, the reference list of the included studies was hand searched for additional missing studies.

Study selection
Identified articles were imported in Endnote (Clarivate Analytics, Philadelphia, USA) to screen for duplicates. Afterward, they were exported into Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia; available at www.covidence.org) for screening and full-text selection. The following inclusion criteria were used to determine eligibility: (1) inclusion of overhead athletes from Olympic or National Collegiate Athletic Association sanctioned collegiate sports (wide participation), (2) use of preseason measures of ROM; (3) tracked injuries at the shoulder and/or elbow throughout the season, and (4) use of a prospective cohort design. Exclusion criteria included the following: (1) sport does not require overhead repetitive activities; (2) inclusion of contact injuries; (3) lower extremity, spine and hand injuries; and (4) full report not published in English. Studies that assessed humeral retroversion were excluded from this review because this physical impairment is not modifiable.26 27 Studies that assessed the effectiveness of specific interventions to reduce the risk of shoulder and elbow injuries were excluded from this review.

Two authors (FP and HAP) independently screened the title and abstract to identify relevant studies for the full-text review. A subsample of 100 studies were randomly selected to calculate the agreement between the two reviewers (Cohen’s kappa=0.88, indicating high level of agreement). During both the title and abstract screening and the full-text review, disagreements between the two authors were first discussed. If consensus was not achieved, a third author (LAM) was consulted to make the final decision regarding inclusion or exclusion.

Assessment of methodological quality
Two authors (PF and HAP) independently scored the methodological quality of each included study using a modified version of the Downs and Black Checklist.28 The Cochrane Handbook recommends the use of this checklist to appraise non-randomised studies.29 The original Down and Black Checklist contains 27 yes/no questions distributed over five sections: reporting, external validity, internal validity (bias and selection bias) and power. Previous systematic reviews that investigated injury risk factors in athletes recommended modifying the Downs and Black Checklist because 6 out of the original 27 questions do not apply to prospective cohort studies.20 30 Further, the score of question number 27 (Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?) was converted into a dichotomous output (yes=1, the study met the a priori sample target; no=0, the study did not report or did not meet the a priori sample target). The modified checklist used in this study had a maximum score of 21 points, which indicated higher methodological quality. For each article, the raw score and the percentage score [(raw score/21 possible points)×100] was reported. During the assessment of methodological quality, disagreements between the two authors were first discussed. If consensus was not achieved, a third author (LAM) was consulted to make the final decision regarding specific scores.

Data extraction
One author (FP) extracted the data, which was checked for consistency by a second author (HAP). The following information was obtained: (1) author, (2) year of publication, (3) sport, (4) study population, (4) sample size, (5) sex, (6) age, (7) participants reporting discomfort or injury at baseline evaluation, (8) participants lost to follow-up, (9) number of participants included in the analysis, (10) number of seasons, (11) injury definition, (12) injury tracking, (13) number of injuries and (14) number of injured participants.

Outcome measures
Injury
An injury was defined as any shoulder-related or elbow-related complaint incurred due to competition or training.31 Injuries to the shoulder and elbow had to be tracked during the season by healthcare personnel, in-season player interview or self-reported questionnaires.

Range of motion
ROM testing procedures, the direction of ROM testing and the side tested were recorded. ROM measurements included two types of variables: (1) absolute ROM of the throwing arm and (2) ROM of the throwing arm expressed as a function of the ROM of the non-throwing arm. The latter often includes a specific ROM cut-off to define the absence or presence of a specific ROM deficit. The type of ROM measure and the cut-off used to identify ROM deficit were extracted for the analysis.

Data analysis
Only ROM variables that were included as predictors in at least three studies were considered for the meta-analysis. For the studies included in the meta-analysis, odds or risk ratios, confidence intervals and p values were extracted. A random-effect meta-analysis was conducted using the method of Mantel-Haenszel stratified by the direction of ROM and the type of measurement (absolute and deficit). The primary outcome was shoulder and elbow injuries. For all ROM measurements, except for shoulder internal rotation difference, the summarised effect estimate was the odds ratios. For shoulder internal rotation difference, Shanley et al12 reported the risk ratio as effect estimate, while Wilk et al32 33 reported the odds ratio. In order to synthesise the data between these studies12 32 33 and to provide an overall estimate, crude odds ratios were converted to crude risk ratios using the formula

\[ RR = OR / (1 - R_0 + (R_0 \times OR)) \]
where RR is the risk ratio; OR is the odds ratio; and R₀ is equal to the risk of a positive outcome in the unexposed group. Summary effect estimates and 95% confidence intervals were reported.

F² statistic assessed the heterogeneity of each ROM meta-analysis. Funnel plot and Egger’s test evaluated publication bias.

RESULTS
Study selection
The database search was completed on 22 September 2018. The search identified 10539 studies (figure 1): 2855 duplicates were removed; 7684 studies were screened; and 93 studies were reviewed in full text. Fifteen studies11–15 32–41 met the inclusion and exclusion criteria and were included.

Study characteristics
Table 1 summarises the characteristics of the included studies. A total of 3314 (female=385) athletes of overhead sports were included in this review, specifically, baseball (n=2471, female=27), softball (n=103, all female), handball (n=535, female=161), tennis (n=65, female=25), volleyball (n=66, female=32) and swimming (n=74, female=37). Six studies included samples of both female and male athletes, but only one considered sex as a covariate in the analysis.19 One study20 included a cohort of baseball and softball players but reported independent analyses for each sport. One study39 included a cohort of youth and adolescent baseball pitchers but reported independent analyses for each age group. A group of authors reported data from the same cohort in two different manuscripts, one that analysed risk factors for shoulder12 and one for elbow injuries.35 Most of the studies followed up athletes for one competitive season. Nine studies tracked injuries across multiple seasons (range of two to eight seasons).11 32 33 35 37 38 40 41 Athletes were re-evaluated at the beginning of each season in seven studies,11 32 33 35 37 38 41 while one considered injuries occurring over a 2-year span.40 After accounting for athletes evaluated for multiple seasons and lost to follow-up, the total included sample was 3750, specifically baseball (n=3026), softball (n=103), handball (n=428), tennis (n=55), volleyball (n=64) and swimming (n=74).

Injury definition varied across studies (table 1). The cumulative shoulder and elbow injury rate in the overall sample of overhead athletes was 17% (666/3750). Divided by sport, the cumulative shoulder and elbow injury rate was 14% (431/3026) for baseball,11 32 33 38 40 9% (9/103) for softball,43% (182/428) for handball,15 39 44% (24/55) for tennis,40 4% (3/64) for volleyball14 and 23% (17/74) for swimming.13

Risk of bias
The average score on the modified Downs and Black Checklist was 14.9±2.1% (range 11–18, online supplementary appendix B). Six studies achieved a score of at least 16, which is greater than 75%.11 13 15 34 36 39

ROM measurements
Shoulder ROM directions included flexion, internal rotation, and horizontal adduction. Shoulder flexion ROM was measured using a standard goniometer with participants supine, and this methodology was consistent across studies.11 32 33 40 Shoulder internal and external rotation ROMs were measured either with a goniometer11 12 14 32 33 38 or a digital inclinometer13 15 35–37 39 41, with participants supine with shoulder abducted at 90° and elbow flexed at 90°. Horizontal adduction ROM was measured with either a goniometer11 12 14 32 33 38 or a digital inclinometer13 15 35–37 39 41, with participants supine with shoulder abducted at 90° and elbow flexed at 90°. Horizontal abduction ROM was measured with either a goniometer11 12 14 32 33 38 or a digital inclinometer13 15 35–37 39 41, with participants supine, according to the procedure described by Laudner et al.42 Further, nine studies11 12 13 32 34 36–39 44 calculated the total rotation of motion by summing internal and external ROMs.

Preseason screening and in-season shoulder and elbow injuries
Methodological differences prevented including the results of eight studies in the meta-analysis.13 14 34 37 38 40 41 43 Three studies32 33 38 from the same group of investigators had overlapping data collection time frames: three competitive seasons, from 2005 to 2008,38 and eight competitive seasons, from 2005 to 2012.32 33 Only the data from the eight competitive seasons were included in the meta-analysis.32 33 Softball players were excluded from the internal rotation deficit meta-analysis because none of the nine softball players with at least 20° of shoulder internal rotation deficit sustained an injury.12 Table 2 summarises the results excluded from the meta-analysis. Shanley et al35 used a receiver operating characteristics curve to calculate the preseason cut-off of shoulder ROM deficit with the highest sensitivity for risk of shoulder and elbow injuries. In adolescent baseball pitchers, a shoulder internal rotation deficit of at least 13° and a shoulder horizontal abduction deficit of at least 15° were associated with a 5.8 and 4.1 greater risks of shoulder and elbow injuries.35 The same analysis did not produce any significant results in youth baseball pitchers.35 Shanley et al35 reported that high school baseball players with deficit of shoulder internal rotation ROM greater than 25° are at higher risk (risk ratio=4.8) of injury. In contrast, Tyler et al36 reported that high school pitchers with no internal rotation deficit (side-to-side difference of less than 0°) are at higher risk of shoulder and elbow injuries (risk ratio=4.9).
Table 1: Study characteristics

<table>
<thead>
<tr>
<th>Sport</th>
<th>Population</th>
<th>Sample</th>
<th>Sex</th>
<th>Age*</th>
<th>Discomfort or injury at baseline</th>
<th>Lost to follow-up</th>
<th>Included in the analysis</th>
<th>Seasons</th>
<th>Injury definition</th>
<th>Injury tracking</th>
<th>Injuries</th>
<th>Injured players</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andersson et al</td>
<td>Handball</td>
<td>329</td>
<td>168 M</td>
<td>NR</td>
<td>155 past SH pain; 56 SH problem last 7 days</td>
<td>92</td>
<td>267</td>
<td>1</td>
<td>Overuse SH injury (OSTRC score &gt;40)</td>
<td>OSTRC questionnaire (six times during the season)</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>Claren et al</td>
<td>Handball</td>
<td>206</td>
<td>M</td>
<td>24.0 (40)</td>
<td>154 past SH pain; 65 SH pain at baseline</td>
<td>42</td>
<td>161</td>
<td>1</td>
<td>Overuse SH injury (OSTRC score &gt;40)</td>
<td>OSTRC questionnaire (15 times during the season)</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>Camp et al</td>
<td>Baseball</td>
<td>81</td>
<td>M</td>
<td>27.9 (4.5)</td>
<td>132 (51 tested multiple seasons)</td>
<td>4</td>
<td>SH or EL injury that caused missing at least one practice or game</td>
<td>Athletic trainer or physician</td>
<td>25</td>
<td>SH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oyama et al</td>
<td>Baseball</td>
<td>832</td>
<td>M</td>
<td>16.5 (1.2)</td>
<td>832 (tested multiple seasons)</td>
<td>3</td>
<td>SH or EL injury that caused missing</td>
<td>Weekly email completed by athletic trainer</td>
<td>25</td>
<td>SH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sakata et al</td>
<td>Baseball</td>
<td>583</td>
<td>M</td>
<td>36.6 (1.2)</td>
<td>176 previous SH or EL pain (excluded from analysis)</td>
<td>64</td>
<td>353</td>
<td>1</td>
<td>Medial EL pain during throwing with abnormal sonography or pain during clinical assessment</td>
<td>Diaries to record elbow or shoulder pain daily</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Shanley et al</td>
<td>Baseball</td>
<td>47</td>
<td>M</td>
<td>9.9 (1.2)</td>
<td>Exclusion criteria</td>
<td>NR</td>
<td>115 (tested multiple season NR)</td>
<td>3</td>
<td>SH or EL injury that caused missing at least one practice or game</td>
<td>Team athletic trainer or study physical therapist evaluated reported complaint</td>
<td>9 SH</td>
<td>10 EL</td>
</tr>
<tr>
<td>Shitara et al</td>
<td>Baseball</td>
<td>132</td>
<td>M</td>
<td>16.3 (0.6)</td>
<td>41 past SH pain; 57 past EL pain; 17 current SH pain; 25 current EL pain</td>
<td>27</td>
<td>105</td>
<td>1</td>
<td>SH or EL injury that caused missing at least 8 days</td>
<td>Injuries reported at medical check-ups</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Tyler et al</td>
<td>Baseball</td>
<td>101</td>
<td>M</td>
<td>NR</td>
<td>166 (42 tested multiple seasons)</td>
<td>8</td>
<td>SH or EL injury that caused missing at least one practice or game</td>
<td>Injuries recorded by athletic trainer or physical therapist of each team.</td>
<td>19 SH</td>
<td>9 EL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilk et al</td>
<td>Baseball</td>
<td>296</td>
<td>M</td>
<td>24.7 (41)</td>
<td>805 (246 tested multiple seasons)</td>
<td>8</td>
<td>EL injury requiring placement on the disabled list</td>
<td>Athletic trainers or internet databases</td>
<td>49</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilk et al</td>
<td>Baseball</td>
<td>122</td>
<td>M</td>
<td>25.6 (41)</td>
<td>170 (68 tested multiple seasons)</td>
<td>3</td>
<td>SH injury causing limited participation or inability to play</td>
<td>Head athletic trainer and team physician</td>
<td>33</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilt et al</td>
<td>Baseball</td>
<td>296</td>
<td>M</td>
<td>24.7 (41)</td>
<td>805 (246 tested multiple seasons)</td>
<td>8</td>
<td>SH injury requiring placement on the disabled list</td>
<td>Athletic trainers or internet databases</td>
<td>75</td>
<td>51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helm et al</td>
<td>Tennis</td>
<td>45</td>
<td>M</td>
<td>15.5 (2.5)</td>
<td>Exclusion criteria</td>
<td>10</td>
<td>55</td>
<td>2</td>
<td>SH or EL injury that caused missing at least one practice or game</td>
<td>Players contacted the investigator if they had an injury</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Forthomme et al</td>
<td>Volleyball</td>
<td>66</td>
<td>M</td>
<td>34.3 (23.2)</td>
<td>32 history of SH pain in dominant shoulder</td>
<td>2</td>
<td>64</td>
<td>1</td>
<td>SH pain that caused absence from sport between 1 and 3 weeks</td>
<td>Weekly questionnaire about shoulder pain</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Walker et al</td>
<td>Swimmers</td>
<td>74</td>
<td>M</td>
<td>15.0 (1.0)</td>
<td>Exclusion criteria</td>
<td>1</td>
<td>74</td>
<td>1</td>
<td>SH pain that interfered with competition or training and lasted at least 2 weeks</td>
<td>Weekly diary about injury status</td>
<td>17</td>
<td>17</td>
</tr>
</tbody>
</table>

*Reported as mean (SD).†Included in the meta-analysis.
‡The authors acknowledged the inclusion of injuries that were acute flare-ups of chronic problems, and long-term problems initially caused by an acute trauma or purely caused by an acute trauma. EL, elbow; F, female; M, male; NR, not reported; OSTRC, Oslo Sports Trauma Research Centre Overuse Injury Questionnaire; SH, shoulder.
### Table 2 Summary of the results from the study that were not included in the meta-analysis

<table>
<thead>
<tr>
<th>Shoulder flexion</th>
<th>Shoulder internal rotation</th>
<th>Shoulder external rotation</th>
<th>Shoulder total rotation</th>
<th>Shoulder horizontal adduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute</td>
<td>Deficit*</td>
<td>Absolute</td>
<td>Deficit*</td>
</tr>
<tr>
<td>Oyama et al.</td>
<td></td>
<td></td>
<td>NI†</td>
<td></td>
</tr>
<tr>
<td>Sakata et al.</td>
<td></td>
<td></td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Shinley et al.</td>
<td></td>
<td></td>
<td>NI</td>
<td></td>
</tr>
<tr>
<td>Adolescent</td>
<td></td>
<td>&gt;13°: 5.8‡(1.6, 20.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Youth</td>
<td></td>
<td>NS¶</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseball</td>
<td></td>
<td>≥25°: 4.8** (2.1, 11.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Softball</td>
<td></td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tyler et al</td>
<td></td>
<td>&lt;0°: 4.9†† (1.0 to 23.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilk et al</td>
<td></td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hjelm et al</td>
<td></td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forthomme et al</td>
<td></td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walker et al</td>
<td></td>
<td>&lt;93°: 24.9‡‡ (2.3, 262.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;100°: 23.0‡‡ (2.2, 236.8)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Range of motion of the throwing arm expressed as a function of the non-throwing arm.
†Analysis compared risk ratio in three groups: below normal, normal and above normal (mean±1 SD used for group definition).
‡Analysis based on the area under the curve of a receiving operating characteristic curve. The odds ratio of the angle cut-off that maximized sensitivity was reported because the authors believed that the cost of participating in a prevention programme is lower than the potential lack of identification of adolescent pitchers at risk of injury.
§Odds ratio
¶Specific effect estimates were not reported in the results.
**Risk ratio.
††Risk ratio for high school pitchers with below-normal internal rotation loss (<0°) compared with pitchers with above-normal internal rotation loss (≥20°).
‡‡Unadjusted odd ratios. Odd ratios adjusted for swim distance (km): <93°: 32.5 (2.7, 389.6) p=0.02 and >100°: 35.4 (2.8, 441.9) p=0.02.
NI, not included in the multivariate predictive analysis; NS, not a significant predictor (odds or risk ratios not reported).

Compared with pitchers with a loss of internal rotation of at least 20°, Walker et al. reported that swimmers with low (<93°) and high (>100°) absolute shoulder external rotations are at risk of a shoulder injury (odds ratios=24.9 and 23.0, respectively) compared with swimmers with shoulder external rotation within 93° and 100°. The odds ratios increased to 32.5 (external rotation <93°) and 35.4 (external rotation >100°) when the statistical model included swimming training distance. Prospective studies in softball, tennis, and volleyball players showed that pre-season shoulder ROM is not associated with in-season shoulder and elbow injuries.

Meta-analyses included data from prospective cohorts of baseball and handball players. Two studies reported effect estimates that were adjusted based on baseline characteristics (detailed information reported in figure 2). Independent meta-analyses evaluated absolute shoulder ROM of external rotation, internal rotation, and total rotation. Other studies measured the absolute value of internal and external rotations, as well as total rotation, but the methodological differences prevented from including these studies in the respective meta-analysis. Only one study measured the absolute value of shoulder flexion and shoulder horizontal adduction. The results of the meta-analyses indicated that absolute shoulder ROM is not associated with shoulder and elbow injuries (figure 2). A large degree of heterogeneity between studies was found for the absolute value of shoulder horizontal adduction (I²=62.1%, p=0.07) ROMs.
Figure 2  Forest plot indicating the meta-analysis results for all preseason ROM screening and subsequent risk of shoulder and elbow injuries. The summarised effect estimate was the odds ratios for absolute external, internal and total rotation and external and flexion deficit. The summarised effect estimate for internal rotation deficit was the risk ratio. a, adjusted for history of shoulder surgery. b, adjusted for sex and history of shoulder pain during the last season. c, adjusted for sex and shoulder pain at baseline. d, adjusted for player position (back player) and history of shoulder surgery. e, authors reported poor inter-rater and intrarater reliabilities of ROM measurements. CI, confidence interval; OR, odds ratio; ROM, range of motion; RR, risk ratio.

In contrast, a large degree of heterogeneity between studies was found for shoulder flexion difference ($I^2=71.4\%, p=0.03$).

Overall, the funnel plot was fairly symmetrical and contained within the borders of the funnel, indicating limited publication bias (figure 3). However, there is some evidence of publication bias for external rotation ROM deficit. The funnel plot positive asymmetry suggests that negative or null studies are missing from the published literature. Last, there was no evidence of small study bias ($p=0.35$).

**DISCUSSION**

This systematic review summarised the available evidence, evaluated methodological quality and analysed whether preseason screening of shoulder ROM is associated with the risk of shoulder and elbow injuries in overhead athletes. Overall, we identified 15 prospective cohort studies,11–15 32–41 with the majority focusing on baseball. Limited evidence was available for other overhead sports, such as handball, softball, volleyball, swimming and tennis. Female athletes are under-represented, accounting for 12% of the overall sample (34% after removing studies on baseball, which is a male-predominant sports). Only one prospective cohort study of a female-predominant sport of softball12 was identified for this review. Our overall hypothesis that preseason shoulder ROM across all overhead athletes identifies those at risk for upper extremity injuries was not confirmed. Summarising the evidence for the meta-analysis was challenging due to the methodological differences between studies. The meta-analysis included three shoulder absolute ROM variables (external, internal and total rotations) and three shoulder ROM deficit (flexion, internal rotation and external rotation). The results of the meta-analysis indicated that professional baseball pitchers were at higher risk of shoulder and elbow injuries when

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**Review**

<table>
<thead>
<tr>
<th>Absolute external rotation</th>
<th>%</th>
<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camp et al. 2017</td>
<td>1.08 (1.00, 1.13)</td>
<td>75.14</td>
<td></td>
</tr>
<tr>
<td>Clausen et al. 2014</td>
<td>0.83 (0.68, 1.01)</td>
<td>3.37</td>
<td></td>
</tr>
<tr>
<td>Anderson et al. 2017</td>
<td>1.05 (0.93, 1.21)</td>
<td>21.59</td>
<td></td>
</tr>
<tr>
<td>Overall (I-squared = 5.1%, p = 0.346)</td>
<td>1.05 (0.99, 1.11)</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

**External rotation deficit**

<table>
<thead>
<tr>
<th>%</th>
<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camp et al. 2017</td>
<td>2.40 (1.93, 3.24)</td>
<td>60.52</td>
</tr>
<tr>
<td>Wilk et al. 2014</td>
<td>1.30 (1.06, 1.59)</td>
<td>20.90</td>
</tr>
<tr>
<td>Wilk et al. 2015</td>
<td>2.20 (1.04, 1.16)</td>
<td>48.56</td>
</tr>
<tr>
<td>Overall (I-squared = 0.0%, p = 0.520)</td>
<td>1.90 (1.24, 2.90)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**Absolute internal rotation**

<table>
<thead>
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<th>%</th>
<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson et al. 2017</td>
<td>1.16 (1.00, 1.34)</td>
<td>41.78</td>
</tr>
<tr>
<td>Shibara et al. 2011</td>
<td>0.95 (0.91, 1.00)</td>
<td>55.49</td>
</tr>
<tr>
<td>Clausen et al. 2014</td>
<td>0.84 (0.64, 1.12)</td>
<td>2.28</td>
</tr>
<tr>
<td>Overall (I-squared = 71.9%, p = 0.028)</td>
<td>1.02 (0.85, 1.23)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**Internal rotation deficit**

<table>
<thead>
<tr>
<th>%</th>
<th>RR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilk et al. 2014</td>
<td>1.69 (1.40, 2.04)</td>
<td>37.25</td>
</tr>
<tr>
<td>Shablay et al. 2011</td>
<td>2.20 (1.70, 5.00)</td>
<td>31.06</td>
</tr>
<tr>
<td>Wilk et al. 2015</td>
<td>0.85 (0.62, 1.16)</td>
<td>31.88</td>
</tr>
<tr>
<td>Overall (I-squared = 30.5%, p = 0.299)</td>
<td>1.11 (0.57, 2.18)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**Absolute total rotation**

<table>
<thead>
<tr>
<th>%</th>
<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clausen et al. 2014</td>
<td>0.77 (0.56, 1.09)</td>
<td>8.39</td>
</tr>
<tr>
<td>Anderson et al. 2017</td>
<td>1.02 (0.98, 1.11)</td>
<td>43.93</td>
</tr>
<tr>
<td>Shibara et al. 2011</td>
<td>0.88 (0.90, 1.00)</td>
<td>47.69</td>
</tr>
<tr>
<td>Overall (I-squared = 62.1%, p = 0.071)</td>
<td>0.99 (0.91, 1.08)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**Flexion deficit**

<table>
<thead>
<tr>
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<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilk et al. 2014</td>
<td>2.80 (1.30, 5.95)</td>
<td>36.90</td>
</tr>
<tr>
<td>Camp et al. 2017</td>
<td>2.83 (1.04, 7.73)</td>
<td>31.39</td>
</tr>
<tr>
<td>Wilk et al. 2015</td>
<td>0.68 (0.62, 1.14)</td>
<td>32.01</td>
</tr>
<tr>
<td>Overall (I-squared = 71.4%, p = 0.036)</td>
<td>1.72 (0.84, 3.56)</td>
<td>100.00</td>
</tr>
</tbody>
</table>
the throwing arm external rotation was not at least 5° greater than the non-throwing arm. Therefore, screening shoulder external rotation ROM may be valuable in professional baseball pitchers.

Risk of bias
Four studies failed to outline the inclusion and exclusion criteria used to select their sample.32 33 37 41 The number of the athletes who were lost to follow-up was clearly described in three studies13 34 39 and five studies reported both the number of athletes that were approached and the number of athletes who agreed to participate.15 34 36 39 40 Therefore, some of the included studies may suffer from selection bias. The investigator responsible for preseason measurements was blinded for hand dominance in three studies12 35 36 exposing the remaining studies to potential investigator bias. Only five studies adjusted the analysis for potential confounders.11 15 32 39 Three studies calculated the required sample size a priori12 34 36; two studies met their target sample size34 36; one study recruited 82% of the estimated sample due to limited time to perform preseason screening.12 Therefore, the majority of the studies may lack sufficient sample size. Three studies did not report the investigator reliability in collecting shoulder ROM.11 34 37 Andersson et al38 reported poor inter-rater and intrarater reliabilities for their ROM measurements, which are a critical threat to internal validity that can bias their results.

Baseball
The risk of shoulder or elbow injuries increased almost twofold if the throwing shoulder of professional baseball pitchers did not have at least 5° greater external rotation compared with the non-throwing shoulder. It is well accepted that the throwing arm of overhead athletes displays greater external rotation ROM compared with the non-throwing arm.44 45 Greater shoulder external rotation increases the amount of motion available to develop ball velocity.46–48 Professional baseball pitchers with less throwing arm external rotation may employ other strategies, such as dropping their arm slot or allowing their arm to lag behind, to maintain throwing performance, which may place them at higher risk of injury.49 50 The fact that less throwing arm shoulder external rotation was associated with shoulder or elbow injury in two independent cohorts of professional baseball pitchers further corroborates the value of screening external rotation ROM in this population.11 21 32 The ultimate goal of athlete screening is to reduce their risk of injury by intervening on modifiable risk factors.21 Therefore, randomised clinical trials that compare the efficacy of the screening and intervention programme compared with usual training and prevention programmes only are necessary to fully understand the value of screening for shoulder external rotation deficit in professional baseball pitchers.

In contrast, younger baseball pitchers and position players (age 7–18 years) do not consistently display differences in shoulder external rotation in the throwing arm compared with the non-throwing arm.51 Although not included in the meta-analysis, four studies34 36 37 41 failed to find a positive association between shoulder external rotation difference and subsequent risk of shoulder or elbow injuries in cohorts of junior and high-school baseball players. Bullock et al17 found no absolute differences of preseason shoulder external rotation ROM between a group of high school baseball players who suffered an in-season shoulder or elbow injury and a group who did not. Adaptation of shoulder external rotation ROM may occur over several years of playing and with increased level of performance, which may explain the findings in younger cohorts.
The current meta-analysis indicates that a shoulder internal rotation difference of at least 20° between the throwing and the non-throwing arms is not associated with future shoulder and elbow injuries. The heterogeneity of the studies included in the meta-analysis, which combined professional baseball pitchers and high school baseball players, remains high. Therefore, while the results suggest that a shoulder internal rotation difference of at least 20° between the throwing and the non-throwing arms is not associated with future shoulder and elbow injuries, future studies should be conducted to clarify the role of shoulder internal rotation in preventing these injuries.

**Limitations**

We acknowledge several limitations. Few prospective studies were identified for sports such as handball, softball, tennis, volleyball, and swimming. The small number of studies included in each meta-analysis (3 out of 15, 20%) is a significant limitation. With few studies, coverage of the overall effect size is of concern, and one cannot be certain that one large study is not determining the overall effect. Statistical power is limited when the number of studies is low. Lastly, the small number of studies prevented subgrouping within each meta-analysis.

There was a high degree of heterogeneity among studies for age (youth to adults), position in baseball (pitchers only to combined cohort of pitchers and field players), competition level (competitive to professional athletes) and injury definition (overuse questionnaires, league managed disable lists, combination of symptoms and sonographic findings, symptom duration, and missing time from sport performance, from one game/practice, up to 3 weeks). Combining studies with substantial heterogeneity may also explain the contradictory results. Clarsen et al included only male handball players, while Andersson et al included both male and female. Each study used different confounders to adjust their analysis. Although both studies used the same definition of overuse injury consistent with a non-contact injury mechanism, Clarsen et al acknowledged the inclusion of injuries that were acute flare-ups of chronic problems, long-term problems initially caused an acute trauma or purely caused by an acute trauma. The inclusion of acute injuries may also explain the higher injury rate (52%) reported by Clarsen et al compared with the study of Andersson et al (22%).

While swimmers have different biomechanical demands compared with throwing sports, shoulder pain and injuries are common due to the high repetitions of overhead motion and training volume. Based on the results of one study, swimmers with external rotation ROM in the low and high tertiles are at higher risk of shoulder and elbow injuries compared with swimmers whose shoulder external rotation ROM is within 93° and 100° (middle tertile). These results are independent of swimming training distance. This ideal external rotation ROM may be protective against shoulder injury, but confirmation of this finding in a second independent cohort of swimmers is needed before making strong recommendations for the use of shoulder ROM screening in this population.

Absolute shoulder ROM or shoulder ROM deficits were not associated with shoulder or elbow injury in high school softball players, shoulder pain in professional volleyball players, or upper extremity injury in tennis players.

**Other overhead sports**

The evidence available for other overhead sports was limited to two prospective cohorts from the same group of researchers for handball, and one prospective cohort each for softball, volleyball, tennis and swimming.

The two studies that screened absolute shoulder ROM of the throwing arm in handball players found opposite results. Clarsen et al reported a small positive association between shoulder total rotation ROM and injury and no association for internal rotation ROM. In contrast, Andersson et al reported a small positive association between shoulder internal rotation ROM and injury and no association for total rotation ROM. Caution is warranted when interpreting the results from Andersson et al due to the poor inter-rater and intra-rater reliability of the ROM measurements. These studies also have some methodological differences that may, in part, explain these contradictory results. Clarsen et al included only male handball players, while Andersson et al included both male and female. Each study used different confounders to adjust their analysis. Although both studies used the same definition of overuse injury consistent with a non-contact injury mechanism, Clarsen et al acknowledged the inclusion of injuries that were acute flare-ups of chronic problems, long-term problems initially caused an acute trauma or purely caused by an acute trauma. The inclusion of acute injuries may also explain the higher injury rate (52%) reported by Clarsen et al compared with the study of Andersson et al (22%).

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Absolute shoulder ROM or shoulder ROM deficits were not associated with shoulder or elbow injury in high school softball players, shoulder pain in professional volleyball players, or upper extremity injury in tennis players.
between screening and injury. Future studies should investigate whether more frequent in-season screenings of factors theorised to relate to injury risk provide better identification of overhead athletes at risk of injury. Most of the included studies did not account for previous injury or exposure (ie, frequency of sport-related activities) in the analysis. This is an important limitation as these factors have been linked to injury and can be potential confounders. The aetiology of injury is multifactorial, and shoulder ROM represents only one risk factor for shoulder and elbow injuries. Thus, the results of this systematic review and meta-analysis should be interpreted with caution.

CONCLUSION

Absolute shoulder ROM or shoulder ROM differences do not appear to be consistent risk factors for shoulder and elbow injuries across different overhead athletes. Age, competition level and position should be considered when screening the shoulder ROM of baseball player. Professional baseball pitchers whose external rotation ROM in the throwing arm was not at least 5° greater than their non-throwing arm were twice as likely to sustain in-season shoulder or elbow injuries. Similar findings were not observed in adolescent or high school baseball pitchers. Limited evidence suggested that swimmers with abnormally low or high external rotation are at higher risk of shoulder injuries. Limited evidence suggested that ROM screening may not be effective to identify handball, softball, volleyball and tennis players at risk of shoulder and elbow injuries.

REFERENCES


What is already known

► The repetitive demands of overhead sport lead to side-to-side changes in shoulder range of motion (ROM), such as increased external rotation and decreased external rotation.

However, injured overhead athletes have impairment of shoulder ROM compared with non-injured overhead athletes.

What are the new findings

► Professional baseball pitchers whose external rotation ROM in the throwing arm is not at least 5° greater than the non-throwing arm were twice as likely to sustain in-season shoulder or elbow injuries.

► Limited evidence: swimmers with external rotation of less than 93° or greater than 100° may be at higher risk of shoulder injuries than swimmers whose ROM is between those limits.

► Limited evidence: ROM screening may not be effective to identify handball, softball, volleyball and tennis players at risk of shoulder and elbow injuries.

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Collaborators Robert Edward Johnson.

Contributors FP, HAP and LAM: conception and design of the work, acquisition, analysis and interpretation of data; drafting of the manuscript and revision; and final approval. ES and CAT: design of the work and interpretation of data, manuscript revision and final approval. CB: acquisition and interpretation of data, manuscript revision and final approval. MLW: analysis and interpretation of data, manuscript revision and final approval.

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Provenance and peer review Not commissioned; externally peer reviewed.

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