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REVIEW

WILEY

Shoulder pain and injury risk factors in competitive swimmers: A systematic review

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Abstract

Aim: To synthesize and assess the literature for shoulder pain and injury risk factors in competitive swimmers.

Design: Systematic review with best-evidence synthesis.

Data Sources: CINHAL, SportDiscus, Scorpus, PubMed, and Embase databases from 1966 to April 30 2022.

Search and Inclusion: Cohort, cross-sectional, and case–control studies investigating shoulder pain or injury risk factors in competitive swimmers were included. Quality of eligible studies were assessed using a modified Newcastle–Ottawa scale. Risk factors were divided into four categories: modifiable-intrinsic, modifiable-extrinsic, non-modifiable, and other/secondary.

Results: Of 1356 studies identified, 24 full texts were evaluated for methodological quality, 22 met the criteria and were included in best evidence synthesis. There was no strong evidence supporting or refuting the association between 80 assessed variables and shoulder injury or pain. The swimmers' competitive level (nondirectional), and shoulder muscle recruitment profiles (e.g., increased activity of serratus anterior) exhibited moderate evidence supporting an association. Conversely, internal and external range of motion, middle finger back scratch test, training frequency, specialty stroke, height/weight, sex, and age all had moderate evidence opposing an association. Limited evidence was found for 58 variables, and conflicting for 8. The highest quality study ($n = 201$) suggested high acute-to-chronic workload ratio and reduced posterior shoulder strength endurance are associated with injury.

Conclusions: Due to the paucity of high-quality studies, future prospective studies are needed to reevaluate known risk factor associations over exploring additional potential risk factors. Swimming practitioners should be aware of the nondirectional association of a swimmer's competitive level and pain, as squad changes could impact injury incidence. Moreover, swimmers experiencing shoulder pain may show increased activity in shoulder stabilizers during specific movements. Importantly, shoulder strength-endurance may be the most clinically relevant modifiable intrinsic risk factor.

KEYWORDS
athlete screening, injury prevention, rehabilitation, shoulder injury, shoulder pain, swimming

1 | INTRODUCTION

Swimming is popular as both a form of recreational exercise[1,2] and as a competitive sport, with over 22000 swimmers competing in the National (American) Collegiate Athletic Association 2021–2022 season.[3] As a form of recreation or exercise, swimming has numerous health benefits with relatively minimal stress/load on bones and joints,[4,5] making it a popular activity for all ages.[6] However, competitive swimming involves consistently high training volumes and intensities, increasing the risk of injury.[7]

Notwithstanding swimming's benefits, shoulder pain and injury prevalence and incidence is high in competitive swimmers. Injuries in competitive swimmers are typically ascribed to repetitive tissue strain.[8] This is understandable given that these athletes perform thousands of shoulder revolutions each session for 10–12 sessions/week,[9] with some swimmers covering up to 110km/week.[7] While injuries are observed in the knee, lower back, and hip, the shoulder is undoubtedly the predominant location of pain and injury in competitive swimmers.[10]

A recent review of injury in competitive swimmers reported a total-body injury incidence of 2.6–3.0 injuries per 1000h of swimming and a shoulder-specific injury prevalence of 23%–51% and 33%–41% in men and women respectively.[10] Further, previous research shows self-reported shoulder pain in up to 97% of college-level swimmers ($n=30$; 17M, 13F) during strenuous exercise[11] and 91% of elite junior competitors ($n=80$; 42M, 38F) over a 1-month period.[7] Despite advancements in sports science and rehabilitation, including improved understanding of intrinsic and extrinsic risk factors, shoulder pain and injury prevalence in competitive swimmers has not decreased suggesting missing or misunderstood risk factors. There may even be a rising trend for shoulder injuries given reports of a prevalence of 26% in 1993,[12] 34% in 2002,[13] and 38% in 2012.[14] These consistently high injury rates warrant further investigation into identifying risk factors to guide athlete screening/monitoring and injury prevention programs.

There is a growing body of evidence identifying pain and injury risk factors. Struyf et al.[15] reviewed the differences musculoskeletal dysfunctions in injured and non-injured swimmer's shoulders. They suggested four key areas for clinicians to be aware of when assessing and treating a swimmer's shoulder: (i) shoulder range of motion (ROM), (ii) shoulder laxity and instability, (iii) shoulder posture, and (iv) scapular dyskinesis. Hill et al.[16] previously conducted a review of shoulder pain and injury risk factors, identifying 18 risk factors, which were categorized into four groups: (i) shoulder joint anatomy and strength, (ii) activity history, (iii) demographics, and (iv) musculoskeletal determinants. This 2015 review included three prospective studies[14,17,18]; however, since this review an additional six prospective studies ($n=457$)[19–24] have been published and should be considered to further our understanding of shoulder injury risk factors in swimmers. There is a clear need to synthesize these data to aid practitioners in their athlete screening and injury prevention strategies. Therefore, this review aims to systematically synthesize the current literature and provide an update on shoulder pain and injury risk factors in competitive swimmers.

2 | METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)[25] and registered on PROSPERO (CRD42021234093).

2.1 | Eligibility criteria

Original cohort, cross-sectional, and case–control studies, published in English were included in this review. To be included, studies must (i) include competitive swimmers aged from 10 to 40years, this included any article that stated their sample was "competitive", (ii) provide a definition of pain/injury (use of a valid pain-scale tool or a positive orthopedic test were accepted), (iii) report an outcome measure including at least one potential shoulder pain or injury risk factor, (iv) use inferential statistics, and (v) in the event of multi-injury/sport studies were only included if shoulder data specific to swimming was presented in isolation. Studies were excluded if they: (i) did not include competitive swimmers, (ii) if nonconservative/surgical interventions were applied, (iii) involved participants with medical conditions without reference to the shoulder, or (iv) involved cadavers and animal specimens.

2.2 | Literature search strategy

A librarian assisted with developing the electronic search strategy. Potentially relevant studies were identified through searching in CINHAL, SportDiscus, Scorpus, PubMed, and Embase databases between 1966 and April 2022 by two authors (S-A.L. and S.D.). The main search strings were "shoulder" AND "pain" OR "injur*" AND "competitive swim" (swim*) AND "risk factor*" (see online supplementary material S1 for full list). Synonyms, Medical Subject Headings (MeSH), Emtree terms, and major concepts derived from the main terms were used to refine our findings. Reference lists of all studies were reviewed for additional studies not found in the original search.

2.3 | Study selection

Articles from the initial database search results were imported into Endnote and duplicates removed. Remaining articles were imported into Rayyan, with two reviewers blinded before screening all titles and abstracts based on the eligibility criteria. In the event of disagreement, a third independent reviewer (S.D.) assisted to reach consensus.

2.4 | Study quality appraisal/risk of bias

Prior to quality assessment of all articles, six articles were chosen at random for independent evaluation to ensure all screening items were clear and understood by three reviewers (A.M., S-A.L., and S.D.). All disagreements were discussed and clarified as a group before quality assessment was conducted. Next, two reviewers (A.M. and S-A.L.) independently evaluated all articles with discrepancies mediated by a third researcher (S.D.).

Quality assessment of all articles was conducted using a modified Newcastle–Ottawa Scale.[26] This scale has previously been used when appraising risk of bias in shoulder injury risk factors in other sporting populations.[27–29] The scale was modified to adjust to the specificity of the review question of interest (online supplementary material S2). Case–control and cohort studies were evaluated on a nine-item scale, with a maximum score of 12, whereas cross-sectional studies were evaluated on a seven-item scale with a maximum score of 10.

Overall method quality was categorized using either high, acceptable, borderline, or unacceptable quality (Table 1). To be included in the analysis a minimum score of >33% of scale items was required, meaning that if a study did not satisfy at least 4 out of 12 (cohort and case control studies) or 4 out of 10 (cross-sectional studies) quality criteria, they were excluded from analysis. This method quality scoring was adopted and modified based on a previous systematic review on shoulder injury risk factors.[30]

2.5 | Data extraction

Two authors (A.H. and S.D.) extracted half of the data into online supplementary material S1 which was then cross-checked (A.M.). Risk factors were categorized into one of four: (i) modifiable-intrinsic, (ii) modifiable-extrinsic, (iii) non-modifiable, and (iv) other/secondary risk factors and defined as follows:

(i) *Modifiable-intrinsic*—any outcome measure with a demonstrated ability to change over time, that are measured on or within the individual (e.g., strength and range of motion (ROM)).
(ii) *Modifiable-extrinsic*—any outcome measure with a demonstrated ability to change over time, that are measured external to the individual, or work performed by an individual (e.g., training load).
(iii) *Non-modifiable*—any measure that has no demonstrated ability to change over time (e.g., injury history).
(iv) *Other/secondary*—any measure that is potentially modifiable but lacks strong evidence regarding their modification (e.g., scapula position).

2.6 | Synthesis of results

This study used best evidence synthesis[31] as an alternative to meta-analysis due to the heterogeneity in outcome measures. This method has been used in the past to present the direction and strength of investigated risk factors.[30] All risk factors were provided an evidence strength, and a direction of association. The strength of evidence was calculated using the criteria previously applied to suit risk factors in overhead sports,[30] Table 2 describes these criteria. The direction of association was indicated using either "for", meaning the evidence supports an association, or "against" meaning the evidence does not support an association.

Several articles reported significant associations in a sub-sample (i.e., different age ranges, or male vs. female) of their study.[7,23,24,32] The synthesized results reported in Table 4 only report associations found overall, with all significant associations found in subsamples

TABLE 1 Criteria and definitions of the overall method quality.

Overall method quality	Cohort and case–control	Cross-sectional
High quality Majority of criteria met. Little to no risk of bias. Results unlikely to be changed by future research	11–12 (>90%)	9–10 (>90%)
Acceptable Most criteria met. Some flaws in the study with an associated risk of bias. Conclusions may change in the light of further research	8–10 (>65%)	7–8 (>65%)
Borderline Crude effect estimates have been presented or have been calculated (thus no confounders have been considered), but the study is otherwise acceptably sound with respect to other possible biases	4–7 (>33%)	4–6 (>33%)
Unacceptable—reject Either most criteria not met, or significant flaws relating to key aspects of study design. Conclusions likely to change in the light of further research	0–3 (<33%)	0–3 (<33%)

Note: Categories of the overall method quality adopted from Asker et al.[30]

TABLE 2 Evidence criteria for best evidence synthesis.

Strong evidence Evidence provided by two or more high-quality studies and by generally consistent findings across these studies (≥75% of the studies reported consistent findings)	
Moderate evidence Evidence provided by one high-quality study and/or multiple studies of acceptable quality and by generally consistent findings (≥75% of the studies reported consistent findings)	
Limited evidence Evidence provided by one study of acceptable quality and/or one or more studies of borderline quality	
Conflicting evidence Inconsistent findings in multiple studies (<75% of the studies reported consistent findings)	

Note: Evidence criteria categories adopted from Asker et al.[30]

reported in-text. Two articles only reported associations in subsamples of their data, with no analyses of the total data presented. When associations were not reported consistently across subgroups, that is, significant associations in one age group but not another, the authors of the original research were contacted and asked to provide their data to allow reanalysis following the methods as described originally (i.e., pooled data rather than in arbitrary age groups).

3 | RESULTS

3.1 | Study selection

From the database search, a total of 1356 studies were identified. After removing duplicates and excluding studies not addressing the objective of our review, 55 studies remained and were screened based on inclusion criteria. Reference lists of the relevant papers were screened, and 5 additional studies were identified and assessed. A total of 24 papers were evaluated for quality, with 22 of these included in the best-evidence synthesis (Figure 1).

3.2 | Study characteristics

Ten of the included studies were cross-sectional designs,[7,13,32–39] seven cohort,[14,19–24] and seven case–control.[40–46] Thirteen studies included both male and female swimmers,[7,14,19–21,23,24,35,38,39,41,42,44] four with females only,[22,32,36,37] two had males only,[13,43] and one failed to disclose participant's sex.[45] Seven studies involved

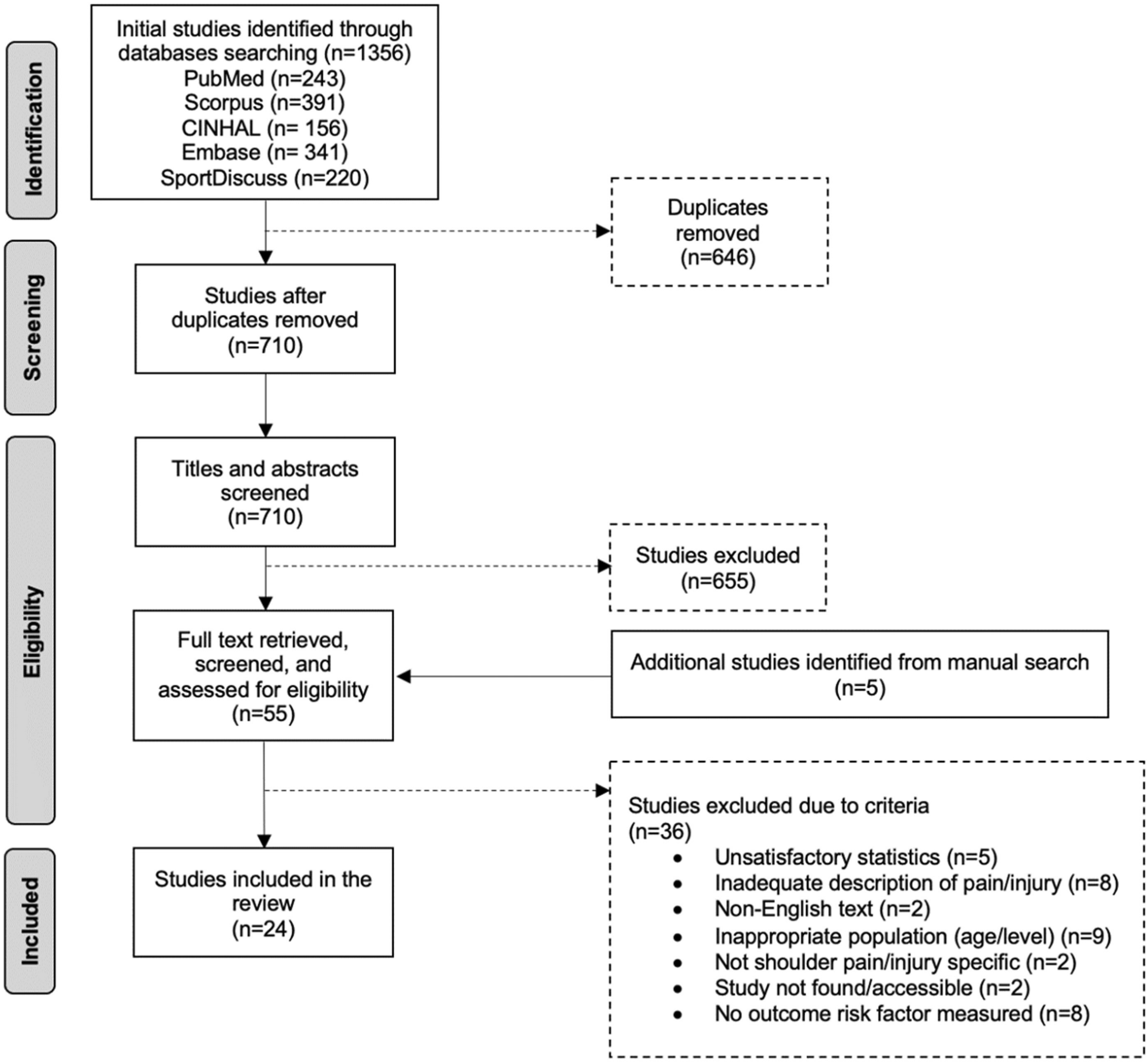

FIGURE 1 Flow diagram of literature search.

international level swimmers,[7,14,21,38,41–43] two studies used division-1 collegiate swimmers,[35,37] two with division-2 collegiate swimmers,[22,36] five studies investigated age-group swimmers,[13,19,20,24,39] and three studies simply reported their participants as competitve swimmers.[23,32,44]

3.3 | Risk of bias within included studies

Table 3 displays the overall method quality score for each study, scoring for individual studies can be found in online supplementary material S3. No studies met the criteria[30] for high-quality methodology. Eleven studies were acceptable quality,[7,14,19–22,24,38,42–44] eleven borderline quality,[23,32–35,37,39–41,45,46] and two were deemed unacceptable and not included in the best evidence synthesis.[13,36] The least commonly met criteria across all studies was the failure to calculate required sample size (see online supplementary material S3).

3.4 | Synthesis of results

The best evidence synthesis is presented in Table 4.

4 | DISCUSSION

This review included 22 studies that investigated at least one shoulder pain or injury risk factor. No study was rated

TABLE 3 Study scores for risk of bias and overall method quality.

Study reference—Separated by research design	Method quality rating	Overall quality
Cross-sectional—Maximum (10)		
Matsuura et al.[38]	7	Acceptable
Sein et al.[7]	7	Acceptable
Bailón-Cerezo et al.[33]	6	Borderline
Bansal et al.[34]	4	Borderline
Beach et al.[35]	4	Borderline
Harrington et al.[37]	6	Borderline
Tate et al.[32]	5	Borderline
Tessaro et al.[39]	4	Borderline
Capaci et al.[13]	2	Unacceptable
Dischler et al.[36]	3	Unacceptable
Cohort—Maximum (12)		
Cejudo et al.[19]	8	Acceptable
Drigny et al.[20]	8	Acceptable
Feijen et al.[21]	10	Acceptable
Lippincott[22]	8	Acceptable
Walker et al.[14]	8	Acceptable
Mise et al.[24]	9	Acceptable
McLaine et al.[23]	7	Borderline
Case–control—Maximum (12)		
Hidalgo-Lozano et al.[42]	9	Acceptable
Sabzehparvar et al.[43]	9	Acceptable
Su et al.[44]	8	Acceptable
Bak et al.[40]	5	Borderline
Hidalgo-Lozano et al.[41]	7	Borderline
Wadsworth and Bullock-Saxton[45]	5	Borderline
Abdelmohsen et al.[46]	5	Borderline

Note: Studies were rated using a modified Newcastle–Ottawa Scale.[26] The maximum score for each study design indicated the lowest risk of bias. The overall quality were then categorized using the Scottish Intercollegiate Guidelines Network (SIGN) (http://www.sign.ac.uk/), as modified by Asker etal.[30], see Tables 1 and 2 for categorization of method quality.

high quality and half of the included articles were borderline, using modified best evidence synthesis criteria.[30] Both muscle recruitment (via surface electromyography [sEMG]) and the swimmer's competitive level had moderate evidence to support an association with shoulder pain or injury. However, there was no direction of association in the swimmers' competitive level, meaning that some studies indicated a higher injury incidence in elite swimmers whereas others indicated a higher incidence in sub-elite swimmers (Table 4). This is likely a result of different training practices of coaches. Similarly, various inconsistent findings were reported regarding muscle activity in injured swimmers compared to non-injured swimmers. Importantly, no study has investigated muscle activity using in-water sEMG, rather opting for non-ecological tasks. Further, while studies consistently report differences in either sEMG amplitude or onset timing, the exact measures have not been replicated between studies. For example, during a standardized functional upper limb task Hidalgo-Lozano et al.[41] reported increased activity of scalene bilaterally in injured swimmers but no changes in upper trapezius. Conversely, Sabzehparvar et al.[43] reported increased upper trapezius, serratus anterior, and latissimus dorsi, but not of middle or lower trapezius (further discussion can be found in Section 4.4).

This review also found a moderate level of evidence against the associations of several measures: external and internal rotational ROM, middle finger distance (back-scratch) test, weight, training frequency (sessions/week), freestyle as a swimmers' specialty stroke, height, and sex. Meta-analysis of data was not possible due to the heterogeneity of studies including the lack of consistency in shoulder pain or injury definitions and limited risk factor reappraisal. Further, when risk factors were reappraised researchers often used alternative methods such as different speeds for the same isokinetic strength test. Overall, this review highlights the dearth of high-quality research investigating possible shoulder injury risk factors in competitive swimmers. We also highlight measures which may, and may not, be relevant in swimmer screening programs and future research.

4.1 | Modifiable-intrinsic risk factors

The literature has examined modifiable-intrinsic risk factors across four key areas, related to: ROM, isometric shoulder strength, isokinetic shoulder strength, and other (non-shoulder) strength and strength endurance. However, no modifiable-intrinsic risk factor had greater than limited evidence in support.

Improving shoulder ROM appears to be a common focus in competitive swimming training and injury prevention programs, evidenced by the 12 articles included in this review that investigated a ROM measure. While several individual studies report significant associations between ROM and shoulder pain or injury,[7,14,19,21,24,34,37] the best evidence synthesis suggests the literature does not support an association with any ROM measure. Of the 13 ROM measures investigated, 35 statistical tests of association were conducted, with only 8 reporting a significant association. There is conflicting evidence regarding the associations of pectoralis minor length, horizontal abduction ROM, glenohumeral laxity, and shoulder rotation

TABLE 4 Best evidence synthesis of shoulder injury risk factors in competitive swimmers.

Risk factor	Studies reporting significant association with risk	Studies reporting no association with risk	Best evidence synthesis (strength, association)
Modifiable-intrinsic risk factors (ROM-related)			
External and internal rotation ROM	Refs. [14,33] $N=214$ (109M, 105F)	Refs. [19,22,24*,32,35,37,38,40] $N=449$ (104M, 344F)	✘
Middle finger distance (back-scratch)		Refs. [24,38] $N=288$ (73M, 215F)	✘
Shoulder flexion	Ref. [21] $N=201$ (96M, 105F)	Refs. [19,32,35] $N=204$ (23M, 181F)	✘
Shoulder extension		Refs. [19,35] $N=56$ (23M, 33F)	✘
Shoulder horizontal adduction		Refs. [19,35] $N=56$ (23M, 33F)	✘
Shoulder adduction		Ref. [19] $N=24$ (15M, 9F)	✘
Triceps brachii length		Ref. [32] $N=148$ (148F)	✘
Latissimus dorsi length		Ref. [32] $N=148$ (148F)	✘
Shoulder abduction		Refs. [19,35] $N=56$ (23M, 33F)	✘
Pectoralis minor length	Ref. [37] $N=37$ (37F)	Refs. [22,32] $N=201$ (201F)	?
Shoulder horizontal abduction	Ref. [19] $N=24$ (15M, 9F)	Ref. [35] $N=32$ (8M, 24F)	?
Glenohumeral laxity (including instability)	Refs. [7,33,34] $N=381$ (275M, 106F)	Refs. [14,22] $N=127$ (37M, 90F)	?
Shoulder rotation width	Ref. [24] $N=76$ (37M, 39F)	Ref. [38] $N=64$ (37M, 39F)	?
Modifiable-intrinsic risk factors (isometric shoulder strength related)			
Flexion strength		Refs. [23,40] $N=100$ (46M, 54F)	✘
Extension strength		Ref. [23*] $N=85$ (37M, 48F)	✘
Flexion:extension strength ratio		Ref. [23*] $N=85$ (37M, 48F)	✘
Supraspinatus strength		Refs. [22,40] $N=68$ (9M, 59F)	✘
Lower trapezius strength		Refs. [22,32] $N=201$ (201F)	✘

(Continues)

TABLE 4 (Continued)

Risk factor	Studies reporting significant association with risk	Studies reporting no association with risk	Best evidence synthesis (strength, association)
Serratus anterior strength		Refs. [22,32] $N = 201$ (201F)	✗
Teres minor, infraspinatus, subscapularis, and upper trapezius strength		Ref. [22] $N = 53$ (53F)	✗
Abduction strength		Refs. [37,40] $N = 52$ (9M, 43F)	✗
Internal rotation strength		Refs. [23,32*,37] $N = 270$ (37M, 233F)	✗
External rotation strength		Refs. [23,32,37] $N = 270$ (37M, 233F)	✗
Internal rotation:external rotation strength ratio		Ref. [23] $N = 85$ (37M, 48)	✗
Scapula depression, abduction, and adduction strength		Ref. [37] $N = 37$ (37F)	✗
Horizontal abduction strength		Ref. [32] $N = 148$ (148F)	✗
Middle trapezius and scapula elevation strength		Ref. [32] $N = 148$ (148F)	✗
Modifiable-intrinsic risk factors (isokinetic shoulder strength related)			
Eccentric external rotation:concentric internal rotation strength ratio	Refs. [20,40] $N = 33$ (19M, 14F)		✓
Eccentric external rotation:eccentric internal rotation strength ratio	Ref. [20] $N = 18$ (10M, 8F)		✓
Concentric and eccentric external:internal rotation strength ratio	Ref. [40] $N = 15$ (9M, 6F)		✓
Concentric external rotation:concentric internal rotation strength ratio		Refs. [20,35] $N = 50$ (18M, 32F)	✗
External and internal rotations torque		Ref. [40] $N = 15$ (9M, 6F)	✗
Eccentric internal rotation:concentric external rotation strength ratio		Ref. [20] $N = 18$ (10M, 8F)	✗
Shoulder abduction:adduction strength ratio		Ref. [35] $N = 32$ (8M, 24F)	✗

TABLE 4 (Continued)

Risk factor	Studies reporting significant association with risk	Studies reporting no association with risk	Best evidence synthesis (strength, association)
Concentric and eccentric external rotation strength		Ref. [40] *N* = 15 (9M, 6F)	✗
Concentric and eccentric internal rotation strength		Ref. [40] *N* = 15 (9M, 6F)	✗
Modifiable-intrinsic risk factors (other strength and strength-endurance measures)			
Weight	Ref. [24] *N* = 76 (37M, 39F)	Refs. [14,19,32,33,39] *N* = 583 (213M, 370F)	✗
Posterior shoulder endurance	Ref. [21] *N* = 201 (96M, 105F)		✓
External rotation strength-endurance	Ref. [35] *N* = 32 (8M, 24F)		✓
Abduction strength-endurance	Ref. [35] *N* = 32 (8M, 24F)		✓
Back static endurance test, ball bridge test, unilateral bridge test, and trunk extension isokinetic strength	Ref. [46] *N* = 30 (16M, 14F)		✓
Closed kinetic chain upper extremity test score		Refs. [22,32] *N* = 201 (201F)	✗
Serratus anterior punch repetition test (strength-endurance)		Ref. [22] *N* = 53 (53F)	✗
Fatigue-related muscle weakness on shoulder shrug and punch		Ref. [44] *N* = 40 (19M, 21F)	✗
Maximal plank time		Refs. [32,37] *N* = 185 (185F)	✗
Internal rotation endurance		Ref. [35] *N* = 32 (8M, 24F)	✗
Adduction endurance		Ref. [35] *N* = 32 (8M, 24F)	✗
Trunk flexion isokinetic strength		Ref. [46] *N* = 30 (16M, 14F)	✗
Body mass index (BMI)	Ref. [33] *N* = 140 (72M, 68F)	Refs. [19,32,39] *N* = 369 (104M, 265F)	✗
Maximal side plank time	Ref. [46] *N* = 30 (16M, 14F)	Refs. [32*,37] *N* = 185 (185F)	?
Modifiable-extrinsic risk factors			
Training frequency (sessions/week)		Refs. [22–24,33,39] *N* = 551 (237M, 314F)	✗

(Continues)

TABLE 4 (Continued)

Risk factor	Studies reporting significant association with risk	Studies reporting no association with risk	Best evidence synthesis (strength, association)
Freestyle as specialty stroke	Ref. [33] $N = 140$ (72M, 68F)	Refs. [7,14,32] $N = 302$ (29M, 223F)	✗
Competitive level	Refs. [7,21,38] $N = 345$ (174M, 171F)		✓
Incorrect hand entry (too lateral)	Ref. [21] $N = 201$ (96M, 105F)		✓
Acute:Chronic workload ratio	Ref. [21] $N = 201$ (96M, 105F)		✓
Dryland warm-up less than five times per week	Ref. [39] $N = 197$ (89M, 108F)		✓
Dryland warm-up greater than 10-minutes	Ref. [39] $N = 197$ (89M, 108F)		✓
Unilateral breathing		Ref. [33] $N = 140$ (72M, 68F)	✗
Training time	Ref. [7] $N = 80$ (42M, 38F)	Refs. [19,23,37,39] $N = 343$ (141M, 202F)	✗
Sprint event as specialty		Refs. [14,39] $N = 271$ (126M, 145F)	✗
Training distance	Refs. [7,24] $N = 156$ (79M, 77F)	Refs. [14,22,33,39] $N = 464$ (198M, 266F)	?
Use of hand paddles	Ref. [33] $N = 140$ (72M, 68F)	Refs. [14,32] $N = 22$ (37M, 185F)	?
Non-modifiable risk factors			
Height		Refs. [14,19,24,32,33,37,39] $N = 499$ (163M, 202F)	✗
Sex	Ref. [39] $N = 197$ (89M, 108F)	Refs. [7,19,33] $N = 244$ (129M, 115F)	✗
Age	Refs. [24,33] $N = 216$ (131M, 105F)	Refs. [14,19,22,23,32,39] $N = 572$ (178M, 394F)	✗
History of shoulder pain or injury	Refs. [14,22,33,34] $N = 428$ (270M, 158F)	Refs. [23,32] $N = 233$ (37M, 196F)	✓
Years of competitive swimming	Refs. [7,33] $N = 220$ (114M, 106F)	Refs. [19,24,32,37,39] $N = 482$ (141M, 341F)	?
Other/secondary risk factors			
Differences in muscle recruitment profiles	Refs. [42,43,45] $N = 92$ (24M, 68[§])		✓
Supraspinatus tendon thickness	Ref. [7] $N = 80$ (42M, 38F)		✓

TABLE 4 (Continued)

Risk factor	Studies reporting significant association with risk	Studies reporting no association with risk	Best evidence synthesis (strength, association)
Differences in pain-pressure threshold	Ref. [41] $N = 34$ (18M, 16F)		Limited evidence, ✓
Fatigue related scapula position	Ref. [44] $N = 40$ (19M, 21F)		Limited evidence, ✓
Scapula dyskinesis		Refs. [22,32] $N = 201$ (201F)	Limited evidence, ✗

Note: Risk factors are presented with studies that found a significant association, studies that found no significant association, and the best evidence synthesis. Strong evidence, moderate evidence, limited evidence, conflicting evidence, ✗ against an association, ✓ in favor of an association, ? unknown association, an * indicates this study found a significant difference in a subsample of their studied cohort.

Abbreviations: F; female; M, male, *N*, total sample size; ROM, range of motion; §, unknown sex.

width and injury. With regards to studies reporting associations, several interesting findings should be highlighted. In a prospective cohort study Walker et al.[14] identified an increased risk of injury in swimmers with glenohumeral external rotational ROM <93° and ≥100°,[14] suggesting there is an optimal window of flexibility. Bansal et al.[34] also reported greater rotational ROM in injured swimmers in a cross-sectional study; however, eight other studies reported no association (Table 4). Further, when assessing males and females separately in a prospective study, Mise et al.[24] reported decreased shoulder rotation width in males, and increased width in females were associated with shoulder pain. Shoulder rotation width is a test whereby the swimmer grasps a rod with both arms in full elbow extension, the minimum hand-to-hand distance the swimmer can move the rod from in front of their torso to behind their torso is the score they receive. A smaller distance indicates greater shoulder complex mobility. Additionally, Mise et al.[24] also found that decreased external rotation ROM was associated with pain in males' right but not left shoulders, and not in either female shoulder. No statistical association was found in the combined data in the left and right shoulders of males and females, as presented in Table 4. The pragmatism of identifying different risk factors between left and right shoulder is questionable, particularly when these findings are not reproduced across sexes. It could be argued that breathing side may influence shoulder kinematics and thereby alter risk between shoulders; however, unilateral breathing has been assessed and found not to be associated with shoulder pain.[32] Finally, while glenohumeral laxity was not associated with shoulder injury,[7,22] Sein et al.[7] did find joint laxity to be associated with impingement and extreme pain. However, these authors concluded that as joint laxity was not associated with training load, it is likely not a main contributor to shoulder pain. Future work should be directed toward investigating the ROM with conflicting evidence.

Improving shoulder strength is also a common focus for land training in swimmers.[47–49] However, of the 27 different isometric and isokinetic shoulder strength measures investigated in six articles, only three significant associations were reported by two articles.[20,40] The three significant associations were various external:internal rotational isokinetic strength ratios.[20,40] In a cross-sectional study, Bak and Magnusson[40] found significantly greater eccentric external rotation:concentric internal rotation in injured swimmers compared to healthy swimmers but reported no difference in concentric external:concentric internal or eccentric external:eccentric internal rotations. Similarly, Drigny et al.[20] reported an eccentric external rotation:concentric internal rotation strength ratio <0.68 had a relative risk of 4.5, with eccentric external rotation:eccentric internal rotation strength ratio also demonstrating predictive ability for shoulder injury risk (<0.66) in their prospective study. It should be noted that this article found no association between concentric external rotation: concentric internal rotation ratio, or eccentric internal rotation ratio: concentric external rotation ratio and shoulder injury. Further investigation should be directed toward understanding the clinical significance of such ratios, especially regarding eccentric shoulder rotator contractions given their absence in swimming. While rotational strength imbalances appear to be associated with shoulder injury, maximal shoulder strength (relative to bodyweight or absolute) does not. However, while current evidence is limited given the lack of replication, it is plausible that shoulder strength-endurance may be more indicative of injury compared to maximal strength.

The highest rated prospective cohort study included in this review investigated the posterior shoulder endurance test and its relationship to shoulder pain.[21] The test, first described in baseball players,[50] involves an athlete laying prone on a plinth with their test arm hanging vertically off the side. The participant then raises their arm to 90° horizontal abduction with a dumbbell weighing approximately 2% of bodyweight, the participant repeats this until volitional exhaustion.[21,50] This exercise has been shown to elicit high levels of activation in trapezius, supraspinatus, and infraspinatus.[50] In their sample of competitive swimmers, Feijen et al.[21] found for every one additional repetition the swimmer performed, their risk of shoulder pain decreased by 5%. Tate et al.[11] modified the posterior shoulder endurance test and found a significant increase toward the end of the season. Unfortunately, this investigation did not statistically analyze the test's relationship with shoulder pain. Beach et al.[35] further support the association of strength-endurance in abduction and external rotation and pain. This cross-sectional study found mean peak torque (after 50 repetitions at 240°/sec) in both external rotation and abduction accounted for 54% and 60% of the variation in shoulder pain rating in left and right arms, respectively. In addition to abduction and external rotation endurance, one case–control study found multiple significant findings relating to various measures of shoulder and core strength-endurance.[46] While being careful not to overstate the clinical relevance of shoulder strength-endurance given its limited evidence, this is perhaps the modifiable-intrinsic risk factor with the greatest supporting evidence. When combined with its capacity to be modified with appropriate shoulder injury prevention programs, strength-endurance has potential to be a highly clinically relevant measure. Due to the impact of shoulder fatigue during swimming, it is possible that increased endurance of the posterior rotator cuff can enhance the stability of the humeral head in the glenoid. In turn, this may help mitigate the shoulders tendency for functional impingement, particularly during longer swimming sets.[51] Future studies should reappraise shoulder strength-endurance, particularly the posterior shoulder test, to confirm its association with shoulder pain or injury, and whether any such association is causal or consequent.

4.2 | Modifiable-extrinsic risk factors

Despite 81% of Olympic swimming events taking less than 140 s, training volume is relatively high compared to other cyclical sports.[52] Barry et al.[53] surveyed 31 swim coaches and support staff (78% of whom had >10 years experience in competitive swimming) and found that 96% monitored training distance and 92% measured session rating of perceived exertion (RPE). Of these experts, 38% perceived their training volume monitoring practices to be either "very" or "extremely effective" in preventing injury. However, the current evidence does not support these expert beliefs. This review found moderate evidence against the association of training frequency (sessions/week) and injury, limited evidence against training time, and conflicting evidence supporting an association of training distance and shoulder injury. No included study investigated session RPE.

Although perhaps logical to consider absolute training load (i.e., training time and/or distance) as injury risk factors, only two included articles reported a significant association between injury and training time[7] or distance.[7,24] Mise et al.[24] found injured swimmers swam significantly further than non-injured swimmers when males and females were pooled together. However, when separated by sex, there was a significant difference in females only. Further, Sein et al.[7] found all who swam >20 h/week, or >60 km/week exhibited supraspinatus tendinopathy on MRI, and swimming >15 h/week doubled the chance of tendinopathy while those swimming >35 km/week had four times the rate of supraspinatus tendinopathy. While these absolute training load measures have some individual support as shoulder injury risk factors, the overall evidence is not conclusive. An earlier systematic review of swimming training load and pain, injury, and illness[54] also reported no clear evidence of association between training volume and pain but did present one article[55] that found an association between retrospectively reported yearly training distance and injury. However, this article was excluded from the current study as shoulder injury data were not presented separately from other injuries. Another study[13] did report a significant association between weekly training time and pain but was also excluded from the current study due to unacceptable method quality (see online supplementary material S3).

A possible reason why no clear association is seen between training load and injury is that these absolute measures fail to account for the rate of load application. For example, this monitoring fails to differentiate between swimming 1 km in 50 m maximal efforts, versus 1 km in recovery. An example of a swimmer's relative training load is in their acute:chronic workload ratio. In fact, this ratio was monitored by 31% of coaches in Barry et al.[53] sample of expert practitioners. In swimming, acute:chronic workload ratio has been investigated by one research team who found every 1-unit increase in this ratio lead to a shoulder injury odds ratio of 4.3.[21] However, the use of this metric has been scrutinized for its inaccuracies and statistical artifacts and cannot currently be recommended for use in reducing injury risk.[56] With the advent of water-proof inertial measurement unit's, more specific shoulder measures may become available to monitor including number and velocity of shoulder revolutions, potentially increasing the validity of relative training loads. Such research is currently being conducted in water polo,[57] and should be repeated in swimming populations. Future studies should also consider monitoring internal load including RPE, sleep, and psychological inventories as suggested by Soligard et al.[58]

Further to training load, the swimmer's competitive level had moderate evidence supporting its association with shoulder injury. Two cross-sectional and one cohort study have analyzed competitive level, and all found a significant association.[7,21,38] However, the direction of this association is not clear. Sein et al.[7] found that swimmers who competed at a higher level had greater rates of supraspinatus tendinopathy. Feijen et al.[21] found regional swimmers had a lower injury risk than club swimmers, but no significant differences were present for national versus club, or international versus club swimmers. Matsuura et al.[38] found that elite swimmers who made the Japanese Olympic team had less injury prevalence than the elite swimmers who did not qualify for the Olympics. Matsuura et al.'s study is likely confounded as injured swimmers would likely be underperforming, therefore negatively impacting team selection. While there is moderate evidence suggesting different competitive levels have different injury rates, the relationship between these is not clear and is potentially an artifact of different training volumes or intensities, both in and out of the water.

4.3 | Non-modifiable risk factors

There was moderate evidence against an association between height, sex, and age with shoulder pain. While there was only limited evidence supporting shoulder injury history and future injury, articles reporting an association exhibited dramatic effect sizes.[14,22,33] A history of shoulder injury increased risk of future injury, by 4.7,[33] 7,[22] and 4.1 times.[14] Further, Walker et al.[14] showed those with a shoulder injury history were 11.3 times more likely to sustain a future shoulder injury lasting >2 weeks. These large effects highlight the need for primary injury prevention in adolescent swimmers. However, this may be somewhat inflated due to articles potentially failing to differentiate between an index injury, exacerbation, reinjury, and new injury. These terms have previously been defined in a consensus statement on methodologies for injury surveillance in aquatic sports.[59] All future research should consider adopting these terms to not only avoid the inflation of injury history as a risk factor, but also to improve inter-study consistency allowing for future metanalyses.

4.4 | Other/secondary risk factors

Injured swimmers appear to exhibit different muscle activity profiles when performing functional upper extremity tasks,[41,43] and scapula elevation.[45] This has led to thus far unsupported speculation as being a possible causal mechanism for injury recurrence and suggestions that motor control exercises be used in injury rehabilitation.[41,43,45] Similarly, it has been suggested that swimmers reporting lower pain-pressure thresholds[42] and fatigue-related changes in scapula orientation[44] are at higher risk of injury. However, caution is recommended when concluding these are shoulder pain or injury risk factors. These articles tested swimmers with and without shoulder pain in a single session potentially experiencing some pain inhibition requiring compensatory increases in activity of other muscles. Due to the study designs, it is not possible to conclude whether these other/secondary risk factors were present prior to the shoulder pain or occurred with the presence of pain. This is particularly relevant for Hidalgo-Lozano et al.[41] who claim the presence of trigger points leads to the development of shoulder pain based on the finding that swimmers with painful shoulders presented with active muscle trigger points.

4.5 | Findings from prior reviews

The current study expands upon a 2015 systematic review by Hill et al.[16] who reported joint instability, internal and external rotation ROM, pain history, and the swimmer's competitive level as the shoulder injury risk factors with the highest level of confidence. Our updated evaluation incorporating recent research, challenges the perceived association between rotational ROM and shoulder injury, and downgrades joint laxity to a conflicting evidence. Nevertheless, the updated evidence continues to support the swimmer's competitive level (moderate evidence) and pain history (limited evidence) as variables associated with shoulder injury.

Hill's review also reported several variables associated with shoulder injury but supported with low confidence, the majority of these now contravened by the most recent evidence, including rotational strength, sex, and breathing side. In fact, training volume is the only variable that is still supported by the current evidence. In addition, years of swimming experience and use of hand paddles currently displaying conflicting evidence, adding a layer of complexity to their roles as potential contributors to shoulder injury.

4.6 | Limitations and recommendations

Before swimming practitioners apply any of the current review's findings, it is important to highlight that it is not known whether the presented risk factors are causal or noncausal. This review synthesizes known associations between various measures and shoulder pain and injury, some of these measures may occur concurrently with pain or injury without being an underlying cause. Currently, it is not known if altering any risk factor will decrease injury incidence. Preliminary evidence suggests exercise-based programs in swimmers could reduce shoulder injury incidence.[48,51,60,61] Nevertheless, before meaningful conclusions can be drawn, subsequent investigations should include the following methodological improvements, larger samples, refined pain definitions, and longer monitoring periods. For swimming practitioners looking to use the presented evidence for their athlete monitoring or injury prevention programs, we highlight the following areas for consideration:

- (i) A swimmer's ROM is not likely a predictor of injury. Monitoring changes throughout a season/career may produce meaningful outcomes; however, it is not clear if "improving" ROM is beneficial.
- (ii) Maximal shoulder strength is likely not associated with shoulder injury. While studies have associated various shoulder rotation strength ratios with pain, due to the lack of maximal eccentric contraction during swimming, we do not believe these ratio's to be practically relevant injury risk factors. Improving shoulder strength-endurance may be of more benefit.
- (iii) Monitoring absolute training load as a means of shoulder injury risk is not supported by the literature. Relative training loads and new technologies may be worth consideration.
- (iv) Clinicians and coaches should be aware that previously injured swimmers are at high risk of re-injury. Greater care and monitoring for swimmers with shoulder injury history is needed during their rehabilitation and return-to-swim programming. Efforts in primary injury prevention may be exponentially beneficial.

To improve on the current research, there is a need for highly controlled prospective studies in competitive swimmers. Risk factors presented in this review should be reappraised using the same methods in different populations to validate the measure and cutoff scores.[62] We suggest the need for risk factor reappraisal is greater than the need for additional exploratory investigations given the current body of knowledge. Excluding training load monitoring, potential risk factors are typically monitored at a single time point while the associated injury may occur several months later. Future prospective studies should monitor modifiable-intrinsic risk factors at regular intervals throughout the collection period (e.g., every 1–3 months), reflecting their modifiable nature. Tate et al.[11] have shown many shoulder metrics change throughout the season, including posterior shoulder endurance, horizontal adduction ROM, and internal and external ROM, highlighting the need to regularly monitor. However, this article failed to statistically associate these variables with pain. As more prospective studies are conducted, it is critical for subsequent systematic reviews to consider their approach. These reviews should exclusively include only prospective designs or weight these studies greater than cross-sectional studies due to their inherently greater quality. Future research should adopt the injury definitions defined by Mountjoy et al.[59], this is particularly relevant to the definitions of pain and injury, index injury, exacerbation, reinjury, and new injury. Adopting these definitions will allow future reviews to pool data between studies improving inferences that can be drawn. New technologies, such as inertial measurement units, should be investigated particularly as they relate to relative training loads. Finally, internal training loads such as RPE, sleep quality, and other psychological metrics should be investigated for their possible role in performance and injury.

5 | PERSPECTIVES TO SPORTS MEDICINE

A thorough understanding of shoulder injury risk factors is critical for the development of athlete screening and injury prevention protocols in competitive swimmers. As evidenced in this review, there is contention regarding risk factors, with many researchers exploring new potential risk factors as opposed to confirming existing risk factors in new populations. While it is not known whether the identified risk factors in this review are causal or noncausal, clinicians may use these risk factors to develop screening protocols and injury prevention programs in their athletes.

AUTHOR CONTRIBUTIONS

Initial literature search and title and abstract screening was conducted by Sophie-Alexandra Larequi and Steven Duhig. Article quality assessment was conducted by Alec McKenzie and Sophie-Alexandra Larequi. Data Extraction was completed by Andrea Hams and Steven Duhig and cross-checked by Alec McKenzie. First draft methods were completed by Sophie-Alexandra Larequi. First draft introduction, results, discussion, conclusion, and abstract were conducted by Alec McKenzie. The manuscript first draft was sent to all authors, with multiple rounds of revisions completed Alec McKenzie.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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