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CLINICAL FEATURE
REVIEW

Risk factors for shoulder pain and injury in swimmers: A critical systematic review

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Abstract

Swimming is one of the most popular recreational and competitive sporting activities. In the 2013/2014 swimming season, 9630 men and 12,333 women were registered with the National Collegiate Athletics Association in the USA. The repetitive nature of the swimming stroke and demanding training programs of its athletes raises a number of concerns regarding incidence and severity of injuries that a swimmer might experience during a competitive season. A number of risk factors have previously been identified but the level of evidence from individual studies, as well as the level of certainty that these factors predispose a swimmer to pain and injury, to our knowledge has yet to be critically evaluated in a systematic review. Therefore, the primary objective of this review is to conduct a systematic review to critically assess the published evidence for risk factors that may predispose a swimmer to shoulder pain and injury. Three electronic databases, ScienceDirect, PubMed and SpringerLink, were searched using keywords "(Injury OR pain) AND (Swim*)" and "(Shoulder) AND (Swim*)". Based on the inclusion and exclusion criteria, 2731 unique titles were identified and were analyzed to a final 29 articles. Only articles with a level of evidence of I, II and III were included according to robust study design and data analysis. The level of certainty for each risk factor was determined. No studies were determined to have a high level of certainty, clinical joint laxity and instability, internal/external rotation, previous history of pain and injury and competitive level were determined to have a moderate level of certainty. All other risk factors were evaluated as having a low level of certainty. Although several risk factors were identified from the reviewed studies, prospective cohort studies, larger sample sizes, consistent and robust measures of risk should be employed in future research.

Keywords:

Predisposing, rotator cuff, shoulder, injury, swimming

History

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Introduction

Swimming is one of the most popular recreational and competitive sporting activities. In the 2013/2014 swimming season, 9630 men and 12,333 women were registered with the National Collegiate Athletics Association Swimming and Diving program [1]. Since it was first introduced as an Olympic sport at the 1896 summer games [2], it has essentially developed into an all year-round sport with athletes maintaining significant training load (including swimming, strength and dry land conditioning) after a competitive season has ended [3]. This leads to an increased risk of sustaining an injury, particularly musculoskeletal soft tissue injuries, among swimmers. The repetitive nature of the swimming stroke and demanding training programs of its athletes raises a number of concerns regarding incidence and severity of injuries that a swimmer might experience during a competitive season [4,5]. The most common site of injury is the shoulder [6–8], with supraspinatus tendinopathy being the most common pathology [9–12]. Kennedy and Hawkins [13] first described the condition of "swimmer's shoulder" as a "common, painful syndrome of repeated shoulder impingement in swimmers". It has been reported that 40–91% of swimmers have experienced shoulder pain in and around the shoulder joint [12,14-16]. The shoulder pain may lead to functional impairments, termination of participation and disability [16].

Despite the incidence and severity of shoulder pain and injury in swimmers being well established, there is however a lack of agreement as to the cause of shoulder pain in swimmers. It has been suggested that due to the pervasive and varied nature of *swimmer's shoulder*, it is unlikely that a single cause can adequately address its prevalence [4]. A number of risk factors have however been identified but the level of evidence [17] from individual studies, as well as the level of certainty [18] that these factors predispose a swimmer to pain and injury, to our knowledge has yet to be critically evaluated in a systematic review. Therefore, the primary objective of this review is to conduct a systematic review to critically assess the published evidence for risk

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Table 1. A summary of exclusion criteria applied to identify relevant articles.

1	Commentaries, book chapters, letters, editorials, conference proceedings, case reports, conference, abstracts or non-peer-reviewed articles
2	Studies not conducted in swimmers
3	Studies examining shoulder/upper limb injuries without reference to shoulder pain or injury
4	Studies of other medical/systemic conditions (e.g. diabetes, amyloidosis) without specific reference to shoulder pain/injuries
5	Animal or cadaver studies

Table 2. A summary of inclusion criteria applied to identify relevant articles.

1	The article must include original data
2	The article must be published in English
3	The article must include a minimum of one potential risk factor for shoulder pain or injury in swimmers
4	Provide a definition of pain/injury in the shoulder
5	The article must include an association with the 95% CI, $p < 0.05$

factors that may predispose a swimmer to shoulder pain and injury.

Methods

Search strategy

Published articles that examined potential risk factors for shoulder injuries in swimmers were reviewed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [19]. An electronic database search of SpringerLink, ScienceDirect and PubMed/Medline was conducted using the search terms "*(Injury OR pain) AND (risk* OR incidence) AND (Swim* OR Triath*)*", "*(Injury OR pain) AND (Swim*)*" and "*(Shoulder) AND (Swim*)*". The database search was limited to articles between January 1985 and December 2014. During first round of article identification, all content on swimming was considered. This included consulting current contents, reviews, textbooks, specialized registers or experts in the particular field of study, and by reviewing the references in the studies found. The titles, abstracts and full texts were independently screened by two of the authors (LH and MP). Articles were excluded if they were unrelated to the topic or met the exclusion criteria outlined in Table 1.

Two rounds of reviewing the literature, using the three-step method in each round, was performed. The first round pertained to the review of articles from the search results of the databases and the second round involved reviewing the bibliography lists of identified articles from the first round. Thereafter, the identified articles were critically appraised according to the inclusion criteria outlined in Table 2.

Level of evidence and certainty

The 29 identified articles included in this review were appraised using two established methods, namely level of evidence and level of certainty [17,20], as recently applied in similar systematic reviews [21,22]. According to the hierarchy of evidence, randomized controlled trials and high-quality (all patients were enrolled at the same point in their disease course [inception cohort] with ≥80% follow-up of enrolled patients, large sample sizes, robust methodology), prospective cohort studies are considered to be level I; lower-quality (small sample sizes and weaker methodology), prospective studies and retrospective studies are considered to be level II; case–control and cross-sectional studies are considered to be level III; case series studies are level IV and expert opinions are level V (Table 3) [17]. The authors LH and MP independently ranked each included study according to these criteria. The authors, LH and MP agreed on the level of evidence assigned to each study.

In addition to evaluate the level of evidence of each study, a level of certainty to the risk factor being associated with shoulder injuries in swimming, was also incorporated into this review. The authors, LH and MP ranked each identified risk factor according to the US Preventative Service Task Force [18] as either a high, moderate or low level of certainty. The two authors agreed on the classification of each risk factor. This classification method of the risk factors identified in this review allows for a relative measure of strength that an identified risk factor is associated with shoulder pain in swimmers. The levels are defined as shown in Table 4.

Table 3. Level of evidence (I–V) definitions used for study evaluation, as previously defined by Wright et al. [20] and Obremskey et al. [17].

Level of evidence	Study types
I	Randomized controlled trials and high-quality (large sample sizes, robust methodology) prospective cohort studies
II	Lower quality (small sample sizes, weaker methodology) prospective and retrospective cohort studies
III	Case–control
IV	Case series
V	Expert opinions

Table 4. Level of certainty (high-low) definitions used for risk assessment, as previously defined by Sawaya et al. [18] and modified by Posthumus et al. [22].

Level of certainty	Definition
High	The available evidence includes consistent results from level I studies. These studies provide a good estimate of risk and are unlikely to be strongly affected by future studies
Moderate	The available evidence includes sufficient evidence to determine that there is risk associated with the injury, but confidence in the estimate is constrained by factors such as the sample size and quality of studies, as well as inconsistency of findings across individual studies. As more information becomes available, the magnitude of risk could change or even alter the conclusion
Low	The available evidence is insufficient to assess risk. Evidence is insufficient because of the limited number or size of studies, and inconsistency of findings across individual studies. More information may allow an estimation of risk

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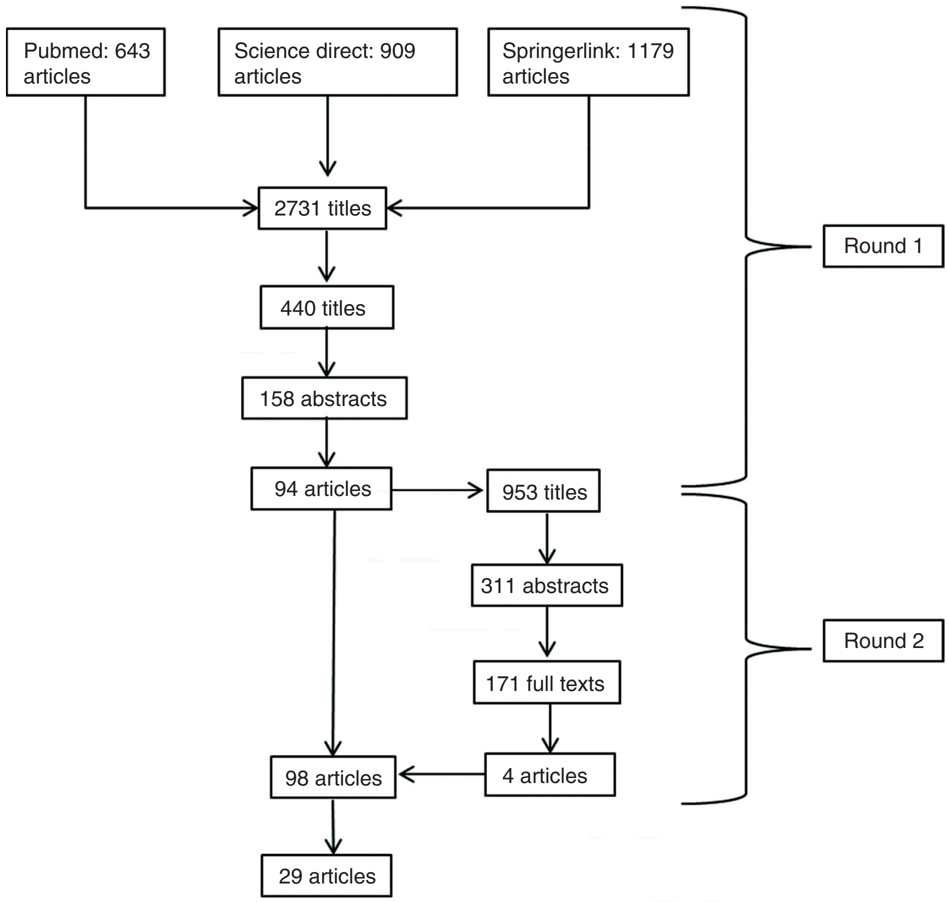

Figure 1. Schematic diagram of systematic review process. Initially, 2731 unique articles (1179 SpringerLink, 909 ScienceDirect and 643 PubMed) were identified. Four-hundred and four, 158 and then 94 articles were identified after sequentially reviewing the titles, abstract and then the full text, respectively. An additional four articles were included from the 953 unique references cited by the original 94 articles. Finally, 69 articles were excluded from this review after inclusion criteria were applied. Therefore, 29 unique and original articles were included in this systematic review. Identified articles were grouped into specific risk factors.

Results and discussion

The article selection process is outlined in Figure 1. In total, the 29 critically appraised articles identified 18 risk factors for shoulder injuries in swimmers which are discussed below and summarized in Table 3 and online Supplementary Table S1. However, a further five risk factors were assigned a low level of certainty as only a single supporting was available. The risk factors identified from the systematic literature search were categorized into four categories based on factors identified during the review process, namely shoulder joint anatomy and strength, activity history, demographics and musculoskeletal anatomy.

Shoulder joint anatomy and strength

Internal/external rotation

Six studies investigated whether the internal/external rotation was associated with shoulder pain in swimmers (see online Supplementary Table S1). Three studies found an association between internal/external rotation and shoulder pain [5,8,23] and three studies found no association [9,24,25]. In a prospective study by Walker et al. [8], increased external range of motion and decreased internal range of motion were associated with significant interfering shoulder pain and significant shoulder injury, after adjusting for swim training exposure. The study divided participants into either low, mid or high external rotation range of motion. The adjusted odds ratios indicated that swimmers in both the low and high external rotation range of motion groups were at increased risk of developing a shoulder injury than those in the mid-range group. Similarly, a cross-sectional study [5] reported a significant reduction in internal rotation range of motion in the 8- to 11-year-old swimmers with shoulder pain compared with those swimmers without pain. However, shoulder range of motion was not associated with shoulder pain in any of the other age groups examined (12–14, 15–18 and Masters). Furthermore, a cross-sectional study by Bansal et al. [23] found that swimmers with shoulder impingement pain had significantly decreased internal range of motion and a significantly increased external range of motion compared with swimmers without impingement pain. Although the term impingement pain has been abandoned due to its generality and poor correlation to what is occurring in the shoulder, Bansal et al. [23] used specific criteria to diagnose impingement pain; this includes 1) history of exercise-related shoulder pain, 2) positive Neer's or Hawkins' impingement test and 3) presence of any of the following – painful arc, tenderness at the greater tuberosity or bicipital groove, painful active contraction or any rotator cuff muscle. However, a case–control [9] and two cross-sectional studies [24,25] failed to find a significant association between shoulder range of motion and shoulder pain. Sample sizes were however limited in these studies that failed to report any association. In summary, there is sufficient evidence that shoulder internal and external rotation range of motion is a risk factor for shoulder pain in swimmers. The confidence in the estimate is however constrained by factors such as sample size, study quality and inconsistency of findings across individual studies. Therefore, the level of certainty that this risk factor is associated with shoulder pain is moderate.

Clinical joint laxity and instability

Six studies examined whether there was an association between clinical joint laxity and instability and shoulder pain. Three studies found an association between clinical joint laxity and instability and shoulder pain [5,23,26] and three studies failed to show an association [8,27,28]. A cross-sectional study by McMaster et al. [26] found a significant correlation between a clinical shoulder exam score for joint laxity and shoulder pain in elite swimmers who reported having shoulder pain. Furthermore, Tate et al. [5] found that shoulder pain was significantly associated with self-reported shoulder instability in swimmers between the ages of 12 and 19 years old but not in Masters swimmers. In addition, the cross-sectional study by Bansal et al. [23] found that atraumatic anterior instability was significantly associated with shoulder impingement pain in swimmers with impingement syndrome, but multidirectional instability was not found to be significantly associated with impingement pain. Bansal et al. [23] defined atraumatic anterior instability as a positive apprehension sign when the tested arm was abducted to 90 degrees and externally rotated. A positive test suggests that there is increased anterior translation of the humeral head with concurrent posterior capsule tightness leading to anterior instability. Multidirectional instability is characterized as generalized capsular laxity and is considered to be atraumatic. There is therefore excessive mobility of the glenohumeral joint in all directions (anterior, posterior, superior and inferior). The tests used were the relocation test with a Sulcus sign and this would constitute a positive test for multidirectional instability. However, two case–control studies [27,28] and a prospective study [8] failed to show that shoulder joint laxity was significantly associated with shoulder pain. In summary, the available evidence suggests that joint laxity and instability is a risk factor for shoulder pain in swimmers, but confidence is constrained by the quality of studies, as well as inconsistency of findings across individual studies. Therefore, the level of certainty that this risk factor is associated with shoulder pain is moderate.

Internal/external rotation strength

Five studies examined whether internal/external rotation strength was associated with shoulder pain. Two studies found an association between internal/external rotation strength and shoulder pain [5,29] and three studies failed to show an association [9,10,25]. A cross-sectional study [5] reported that reduced internal rotation torque was associated with shoulder pain and disability in swimmers with shoulder pain. Although it does not provide evidence that decreased internal/external rotation strength is a risk factor for injury, a randomized control trial by Swanik et al. [29] found a significant decrease in the incidence of shoulder pain between the experimental group who underwent shoulder functional training to strengthen the internal and external rotators compared with the control group. However, two case–control studies [9,10] and a cross-sectional study [25] failed to find an association between internal and external rotation strength and shoulder pain. In summary, due to insufficient evidence, as well as inconsistency among the available studies, the level of certainty that internal and external rotation strength is a risk factor for shoulder pain in swimmers is low.

Shoulder flexibility

Three studies examined whether shoulder flexibility was associated with shoulder pain. Two studies found an association between shoulder flexibility and shoulder pain [30,31] and one study didn't find an association [32]. In a prospective study by Greipp [30], anterior shoulder inflexibility was associated with shoulder pain in male and female swimmers. Similarly, a case–control study by Ozcaldiran [31], found that swimmers with shoulder pain had a significant positive correlation between total flexibility index scores and shoulder pain. However, there was no significant association between swimmers who reported shoulder pain and subjective level of joint flexibility in a cross-sectional study [32]. There is currently a lack of evidence and consistency between findings to suggest that shoulder flexibility is a risk factor for shoulder pain in swimmers. The level of certainty that this risk factor is associated with shoulder pain is therefore low.

Glenohumeral translation

Only two studies examined whether glenohumeral translation was associated with shoulder pain. Both studies found no association between glenohumeral translation and shoulder pain [27,33]. In a case–control study by Borsa et al. [27], no significant difference in glenohumeral joint displacement between swimmers and controls was found. In addition, no difference between joint displacement and swimmers with a history of shoulder pain was found. Furthermore, in a randomized intervention trial by Lynch et al. [33], a significant decrease in forward shoulder translation and forward head angle was found in the intervention group but not in the control group. In the intervention group, a significant increase in shoulder girdle strength was found following the intervention. However, no significant interaction was found in pain score following the intervention and reduction of forward shoulder translation and forward head angle. In summary, there is currently insufficient evidence to suggest that glenohumeral displacement is a risk factor for shoulder pain in swimmers; therefore, the level of certainty is low.

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Activity history

Training load, volume and intensity

Ten studies examined whether training load, volume and intensity was associated with shoulder pain. Four studies found an association between training load, volume and intensity and shoulder pain [5,12,34,35] and six studies didn't find an association [4,8,25,36-38]. A cross-sectional MRI study by Sein et al. [12] reported a significant correlation between training load (number of hours swum per week and weekly mileage) and increased risk of shoulder impingement pain. This study also showed that supraspinatus tendon thickening was significantly correlated with increased hours of training per week, weekly mileage and cumulative shoulder use. Furthermore, two cross-sectional studies [5,34] showed that swimmers who swam a greater number of hours and mileage reported a significantly higher incidence of shoulder pain. Moreover, the retrospective study by Ristolainen et al. [35] showed that injured swimmers had reported swimming significantly more during the 12-month period than the uninjured swimmers and the mean number of kilometers swum was higher in swimmers with at least one injury joint compared to swimmers without an injury. However, the case–control study by Su et al. [36] found no significant difference between practice duration (h/week) or practice distance (km/week) and shoulder impingement and pain in swimmers. Additionally, two recent prospective studies [4,8] reported that mileage and hours of practice were not associated with shoulder pain. Furthermore, two cross-sectional studies [39,38] also failed to find a correlation between shoulder pain intensity and hours per week of training. In summary, the studies which investigated training load, volume and intensity as a risk factor for shoulder pain are inconsistent. Therefore, the level of certainty that this risk factor associated with shoulder pain is low.

Stroke distance and stroke specialty

Eight studies examined whether stroke distance and stroke specialty was associated with shoulder pain. One study found an association between stroke distance and stroke specialty and shoulder pain [40] and seven studies found no association [3,5,8,12,30,34,41]. It has been reported that of all strokes, the butterfly stroke was the most likely to cause shoulder pain in males and females [40]. However, in a prospective study by Walker et al. [8] and a retrospective study by Wolf et al. [3], stroke specialty or stroke distance were not significantly associated with shoulder pain. Furthermore, four cross-sectional studies [5,12,34,41] and a prospective study [30] failed to find a significant association between stroke specialty or stroke distance with shoulder pain in swimmers. In summary, based on the available evidence it is unlikely that stroke distance and stroke specialty is a risk factor for shoulder pain in swimmers. Therefore, the level of certainty that this factor is associated with shoulder pain is low.

Years of swimming experience

Six studies examined whether years of swimming experience was associated with shoulder pain. Two studies found an association between years of swimming experience and shoulder pain [5,12] and four found no association [4,25,38,39]. In a cross-sectional MRI study by Sein et al. [12], increased supraspinatus tendon thickness was associated with years of swimming training experience demonstrated impingement pain and supraspinatus tendon thickening. Furthermore, a cross-sectional study by Tate et al. [5] found an association between swimmers with shoulder pain and years of swimming experience in 15- to 19-year-old swimmers, but not in the other age groups studied. However, in a recent prospective study by Chase et al. [4], years of swimming experience was not significantly associated with shoulder injury. In addition, two further case–control studies [39,38] and a cross–sectional study [25] also failed to find an association between shoulder pain in swimmers and year of previous swimming experience. In summary, since the available evidence to assess years of swimming experience as a risk factor for shoulder pain in swimmer is insufficient, the level of certainty that this factor is associated with shoulder pain is low.

Breathing side

Only two studies examined whether breathing side was associated with pain. One study found an association between breathing side and shoulder pain [5] an one found no association [32]. In a cross-sectional study by Tate et al. [5], bilateral breathing in the 8 to 11-year-old age group was found to be associated with shoulder pain but no associations were found in breathing side preference in the other age groups (12–14, 15–18 and Masters). Further, a cross-sectional study by Stocker et al. [32] failed to find a significant association between breathing side and shoulder pain in competitive collegiate and masters level swimmer. There is inconsistent and insufficient evidence that breathing side is a risk factor for shoulder pain in swimmers and therefore the level of certainty is low.

Swimming training equipment

Four studies examined whether swimming training equipment was associated with shoulder pain. Only one study found an association between swimming training equipment and shoulder pain [40] and three studies found no association [5,32,42]. In a cross-sectional study by McMaster et al. [40], the use of hand paddles and kickboards were found to be significantly associated with shoulder pain in both male and female swimmers with shoulder pain. In three subsequent cross-sectional studies [5,32,42], the use of hand paddles were not significantly associated with shoulder pain or injury. In summary, there is no evidence that training equipment increases the risk of shoulder pain in swimmers. Therefore, the level of certainty that this risk factor is associated with shoulder pain is low.

Cross training and stretching

Four studies examined whether cross training and stretching was associated with shoulder pain. Two studies found an association between cross training and stretching and shoulder pain [30,40] and two studies found no association [8,34].

In a prospective study [30], increased weight training was associated with increased shoulder pain in male swimmers. Furthermore, increased stretching in both males and females was associated with increased incidence of shoulder pain in a cross-sectional study [40]. Additionally, shoulder pain was associated with strength training and weight training for both groups. However, in a prospective study by Walker et al. [8], the number of dry-land strength training sessions per week was not significantly associated with shoulder pain. Moreover, a cross-sectional study by Krüger et al. [34] found that strength training was not associated with shoulder pain or injury. In summary, there is insufficient evidence and inconsistent findings among the individual studies to suggest that cross training and stretching is a risk factor for shoulder pain in swimmers. Therefore, the level of certainty that this risk factor is associated with shoulder pain is low.

Demographics

Previous history of pain and injury

Four studies examined whether history of previous pain and injury was associated with shoulder pain. Three studies found an association between previous history of pain and injury and shoulder pain [5,8,23] and one study found no association [34]. In a prospective study by Walker et al. [8], swimmers with a history of shoulder pain were 4.1 and 11.3 times more likely to sustain a subsequent injury for significant interfering pain in the shoulder and a significant shoulder injury, respectively. A cross-sectional study by Tate et al. [5] found that previous history of pain or injury was significantly associated with shoulder pain in high school swimmers and masters' level swimmers. Moreover, Bansal et al. [23] found a strong association between past history of shoulder pain and shoulder impingement syndrome. However, in a cross-sectional study by Krüger et al. [34], no association between previous history of injury and shoulder pain was found. In summary, there is sufficient evidence from both a level I and two level III studies to determine that previous history of pain and injury is a risk factor for shoulder pain in swimmers. However, due to the inconsistent findings, and lack of repeated level I studies, there is only a moderate certainty that this risk factor is associated with shoulder pain.

Sex

Five studies examined whether sex was associated with shoulder pain. Only one study found an association between sex and shoulder pain [43] and four found no association [4,30,34,36]. A retrospective study by Sallis et al. [43] reported that female swimmers had significantly more shoulder injuries than the male swimmers. However, a prospective study by Chase et al. [4] failed to find a significant difference in injury rates between male and female swimmers over the course of a competitive season. Furthermore, in a prospective study [30], a cross-sectional study [34] and a case–control study [36], it was found that sex was not significantly associated with shoulder pain or injury. In summary, there is insufficient evidence and inconsistencies among the individual studies, to suggest that sex is a risk factor for shoulder pain in swimmers. Therefore, the level of certainty that gender is a risk factor for shoulder pain is low.

Age

Seven studies examined whether age was associated with shoulder pain. All seven studies found no association between age and shoulder pain [4,5,8,25,30,34,36]. In a prospective study by Greipp [30], the incidence of shoulder pain was not significantly associated with age. Similarly, the case–control study by Su et al. [36] found that age was not significantly different between swimmers with impingement and those without. More recently, two cross-sectional studies found no significant association with age of the swimmers and the incidence of shoulder pain [5,34]. In summary, there is currently no evidence that age is a risk factor for shoulder pain in swimmers and its certainty is therefore low.

Competitive level

Four studies examined whether competitive level was associated with shoulder pain. Three studies found an association between shoulder pain and competitive level [12,34,44] and one study found no association [36]. In a description of elite and recreational swimmers [44], the elite group was found to have significantly higher incidence of shoulder overuse dysfunction and pain than the recreational group. In addition, the cross-sectional MRI study by Sein et al. [12] found that competitive level was significantly associated with supraspinatus thickness and impingement pain and that athletes at higher levels of competition were more likely to have supraspinatus thickness and impingement pain than those at lower levels. Furthermore, the cross-sectional study by Krüger et al. [34] reported that competitive swimmers were found to have significantly higher incidence of shoulder pain compared with recreational swimmers. The case–control study by Su et al. [36] did not report an association, however only 20 injured swimmers were investigated and this study was not designed to investigate this risk factor. In summary, the available evidence is sufficient to conclude that competitive swimming, as appose to recreational swimming, is a risk factor for developing shoulder pain. Therefore, the level of certainty that this risk factor associated with shoulder pain is moderate.

Musculoskeletal

Scapular kinematics, strength and dyskinesis

Three studies examined whether scapular kinematics, strength and dyskinesis was associated with shoulder pain. Only one study found an association between scapular kinematics, strength and dyskinesis and shoulder pain [36] and two studies found no association [5,25]. In a study of 20 swimmers with shoulder impingement and 20 healthy swimmers without history of shoulder pain [36]; shoulder impingement was significantly associated with reduced strength during the scapular strength test after swimming. In addition, swimmers with shoulder impingement also demonstrated less upward

Table 5. Summary of the level of certainty of risk factors associated with shoulder injuries in swimmers.

Level of certainty		
High	Moderate	Low
_	Clinical joint laxity and instability	Years of swimming experience
	Internal/external rotation	Training load, volume and intensity
	Previous history of pain and injury	Gender
	Competitive level	Age
		Swimming training equipment
		Stroke distance and stroke specialty
		Breathing side
		Internal/external rotation strength
		Scapular strength
		Scapular dyskinesis
		Core stability
		Glenohumeral translation
		Swimming scholarship status
		Pectoral length
		Tricep length
		Latissimus length
		Inadequate treatment
		Shoulder flexibility

rotation at 45, 90 and 135 degrees of humeral elevation during arm abduction after swim training. Conversely, in the cross-sectional study by Harrington et al. [25], scapular depression, abduction and adduction strength were not significantly associated with shoulder pain. Further, the frequency of obvious scapular dyskinesis was not found to be different between the swimmers who had shoulder pain and those that had no shoulder pain in any age group [5]. In summary, the evidence supporting scapular kinematics, strength and dyskinesis as a risk factor for shoulder pain in swimmers is insufficient and therefore the level of certainty that this risk factor is associated with shoulder pain is low.

Core stability

Only two studies examined whether core stability was associated with shoulder pain. One study found an association between core stability and shoulder pain [5] and one study found no association [25]. In a cross-sectional study by Tate et al. [5], it was reported that youth swimmers (12–14 years old) with shoulder pain maintained a side bridge for significantly less time than uninjured swimmers. There was however no significant differences found in other age groups and between other tests of core stability (prone bridge and close kinetic chain bridge). A further study by Harrington et al. [25] found no association between side bridge and prone bridge endurance and shoulder pain. In summary, the evidence available on trunk muscle endurance as a risk factor for shoulder pain in swimmers is insufficient. Therefore, the level of certainty that this risk factor is associated with shoulder pain is low.

Pectoral length

Only two studies examined whether pectoral length was associated with shoulder pain. Both studies found an association between pectoral length and shoulder pain [5,25]. It has been demonstrated by Borstad and Ludewig [45] that a short pectoralis minor demonstrated scapular kinematics similar to the kinematics exhibited in earlier studies by subjects with shoulder impingement. These results support the theory that an adaptively short pectoralis minor may influence scapular kinematics and is therefore a potential mechanism for subacromial impingement. In a cross-sectional study by Tate et al. [5], a significant association was found in the resting normalized pectoralis minor length (normalized to clavicle length) at rest in the 15-year-old age group of girls with shoulder pain but not in any of the other age groups. Additionally, no associations were found during pectoralis minor stretch and shoulder pain in any of the age categories. Furthermore, the cross-sectional study by Harrington et al. [25] found that pectoralis length at rest and at stretch was significantly associated with shoulder pain in Division I female swimmers. In summary, there is currently inconsistent evidence that pectoralis length is a risk factor for shoulder pain in swimmers; therefore, the level of certainty that this risk factor is associated with shoulder pain is low.

Conclusion

The investigation of risk factors is an important initial step towards the understanding of the etiology of shoulder injuries in swimmers. Although, a number of risk factors were identified in the included studies, poor study methodology or limited available data caused constrained estimation of injury risk to the shoulder for almost all of the investigated risk factors. None of the identified risk factors were found to have a high level of certainty. Prospective cohort design and consistency of measurements of risk should be employed in future studies. Additionally, risk factors that were only investigated by a single study are assigned a low level of certainty as there is insufficient evidence to make a conclusion and require future investigation. These risk factors include: *swimming scholarship status* [3], *inadequate treatment* [23], *triceps length* [5], *latissimus length* [5] and *internal/external rotation endurance* [24]. Furthermore, some studies have suggested that changes in EMG activation of shoulder stability muscles are associated with shoulder pain during swimming [28,39,46-48]. However, further investigation is required in order to determine whether the changes in EMG activation shoulder stability muscles are a possible cause of shoulder pain in swimmers or that shoulder pain modifies EMG activation. Finally, some studies have suggested that a genetic predisposition to shoulder injury exists [49], however; no studies have investigated this in swimmers. It is therefore possible to suggest that overuse injuries in swimmers who have an already high volume of arm rotations may in some way be at additional risk for shoulder injury.

Limitations

There were several limitations to this systematic review. There was a clear lack of consistency of the definition of shoulder pain or injury. A number of studies utilized self-reported pain without an objective diagnosis of pathology. Additionally, several aspects of one shoulder pathology were investigated which may weaken the significance of factors with only a single supporting study. Therefore, it is possible that a single risk factor for shoulder pain such as scapular rotation may possibly be nullified as a risk factor as it doesn't show a correlation with scapular dyskinesis. Secondly, some studies were excluded because they were unavailable or in a foreign language. Finally, the systematic review was limited by the quality of studies available, as the majority of studies were case–control or cross-sectional in study design.

This evidence-based systematic review provides descriptive analysis of several risk factors for shoulder injury in swimmers. Although the identified risk factors did not achieve a high level of certainty, several of the risk factors were moderately associated with shoulder pain and injury in swimming. In order to improve the definition and etiology of shoulder injuries in swimmers, more high-quality studies are required to improve the inconsistency of results. Finally, a shoulder injury can potentially be a career ending happenstance, thus, an understanding of the factors that predispose a swimmer to shoulder injury can improve the quality of training, reduce injury rates and prolong a career.

Declaration of interest

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Supplementary material available online.

Supplementary Table S1.