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Review of Shoulder Injuries and Shoulder Problems in Competitive Swimmers

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Abstract Swimming is a popular sport, both recreationally and competitively. The repetitive nature of the swim stroke places unique demands on the body. Competitive swimmers spend a considerable amount of time training for their sport, and can swim 110km or more a week. As a consequence of this amount of swimming and the repetitive nature of the swimming stroke, swimmers can develop injuries, most commonly localised to the shoulder. This manuscript will focus on shoulder problems in swimmers and present a review of the factors that may predispose an individual to injury. The EBCSOhost Research Database was initially searched using the keywords: "(Swimming OR Swimmers") AND "(Competitive OR Shoulder)" AND "(Injury OR Pain)". This was supplemented by cross-referencing to publications cited by the authors of the initial literature search. Effect sizes (Cohen's *d*) were calculated to compare the different factors associated with shoulder injury. A review of literature split factors associated with shoulder problems into six groups: biomechanics of the shoulder; general swimmer characteristics; injury history; shoulder laxity and range of movement; shoulder strength; general strength. The impact of each factor upon swimming and shoulder injury is discussed and the effect sizes show which factors have the greatest association with shoulder injury in swimmers.

Keywords: *swimming, competitive, shoulder, pain, effect size*

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1. Introduction

Swimming is a popular sport, both recreationally and competitively. An Olympic sport since 1896 [1] swimming is increasingly popular in many countries. In Europe swimming is one of the most popular sports, with nearly 2.9 million people swimming weekly in the UK in 2012-13 [2], and childhood participation in swimming has increased by over 200% in the past 30 years in Ireland [3]. Competitive swimming is also popular with over 330000 swimmers registered with USA swimming in 2014 [4], and at the NCAA Division 1 level, over 8000 swimmers have consistently competed each year at this high level between 1981 and 2013 [5]. However, the difference between recreational and competitive swimming is significant. Recreational swimmers may swim regularly, perhaps weekly or several times per week but competitive swimmers can swim twice per day, covering an average of nearly 42km per week, but this can vary from 9km/week for club level swimmers to 110km/week or more for some international swimmers [6,7,8,9,10]. With a typical stroke count of 8-10 complete strokes per 25m lap [11] this can equate to an average of 13000-16000 rotations (potential range: 2880 to 44000) of each shoulder per week.

The prevalence of shoulder problems in competitive swimmers (the so-called "swimmers' shoulder") is reported to be high, with estimates ranging from 18-91%, incidence generally increasing with age and level of swimmer [6,8,10,12,13,14]. Anecdotal evidence even suggests that shoulder pain is normal and an expected part of swimming if one wants to succeed [9]. One of the major causes of shoulder problems in swimmers is thought to be impingement of the subacromial structures, resulting from repetitive overuse of the shoulder joint [15]. This may lead to a reactive tendinopathy, resulting in tendon swelling [16] and a reduction in subacromial space. The reduced space may then lead to impingement or trapping of soft tissue between the acromion and the humerus. However, it is not clear if the reduction in subacromial space is cause or consequence of shoulder impingement [17]. Even the term '*impingement*' to describe the condition has been replaced as the anatomical explanation of impingement does not account for the pathology associated with the condition. The term *Subacromial Impingement Syndrome* (SIS) or *Subacromial Pain Syndrome* (SPS) is now more commonly used to describe the condition [17,18]. This review will adopt the term Subacromial Impingement Syndrome (SIS) to describe condition resulting from repetitive overuse of the shoulder joint. The cause of SIS seems to be multifactorial, and has been suggested to be due to biomechanical factors, overuse and fatigue of shoulder muscles, and glenohumeral joint laxity. Evidence suggests that increasing the time and distance swum will increase the incidence of shoulder problems and Sein et al. [10] found that in a group of club swimmers aged 13-25, those who swim more than 60km/week or more than 20 hours/week all had supraspinatus tendinopathy. In a biomechanical analysis of the front crawl swimming stroke however, Yanai and Hay [19] suggested that with the correct stroke technique it is possible to swim without any shoulder impingement. Together, correct swim technique and shoulder conditioning then seem critical to limit or even avoid shoulder impingement and shoulder pain. This study aims to review the factors associated with shoulder problems in competitive swimmers.

1.1. Risk Factors for Shoulder Problems

The nature of competitive swimming and the associated practice necessary to compete effectively results in repetitive overuse being one of the major contributors to shoulder problems in swimmers, leading to SIS [15] . A number of studies have reviewed shoulder problems in swimmers. These have looked at stroke biomechanics, overuse and muscle fatigue, upper body posture and mobility, and glenohumeral laxity and subsequent shoulder instability [15,20,21,22,23,24]. We carried out a literature search for studies investigating shoulder problems in swimming. We presented the results of the literature search as effect sizes where possible to allow direct comparison of the relative impact of the different factors on shoulder problems in swimmers.

2. Methods

An institutional subscription to the EBCSOhost Research Databases was used for the preliminary literature search. The search terms used and results are listed in Table 1. The results were limited to those in English, and published since 1980. This was supplemented by cross-referencing to publications not listed in the initial results but cited by authors from the initial literature search. Effect Sizes (Cohen's *d*) were used to measure the magnitude of a treatment effect and allow comparison of the practical significance of quantitative research results, independent of sample size. The results were included in this review if they contained data that allowed calculation of effect sizes according to the method of Thalheimer and Cook [25] such as means and associated standard deviations, or some measure of association such as Odds Ratio or similar, Correlation Coefficients or F-test. All the results are presented as Effect Sizes. Those results not initially presented as effect size were converted using appropriate techniques as follows: Odds ratio, Incident Risk Ratio: Converted using the method described by Chinn [26] and Borenstein et al. [27]; Correlation Coefficients: Converted using the method described by Borenstein et al. [27]; F-test: Converted using the method described by Thalheimer and Cook [25]; Means and Standard Deviation: Converted using the method described by Thalheimer and Cook [25].

The objective of this meta-analysis was to compare the predictive value of different factors for shoulder problems. To provide a framework for comparison of different effect sizes, a Cohen's *d* value of 1 shows the group means differ by 1 standard deviation. The convention described by Cohen [28] was adopted of Small Effect Size: d=0.2; Medium Effect Size: d=0.5; Large Effect Size: d=0.8. In all, from the literature search and from cross referencing to other studies, 13 studies presented results in a form that allowed the calculation of effect sizes.

Table 1. Search terms and results from literature search

Search	Field	Search Term	Results	New Hits
1	Abstract	Swimming AND Competitive AND Injury	85	-
2	Abstract	Swimming AND Shoulder AND Pain	96	78
3	Abstract	Swimmers AND Competitive AND Injury	73	24
4	Abstract	Swimmers AND Shoulder AND Pain	108	63

2.1. Shoulder Pain vs. Shoulder Impingement

Throughout this review we will use the term shoulder problems as the studies included mainly used two methods of identifying shoulder problems in swimmers: presence/history of shoulder pain and presence of shoulder impingement. Some studies used questionnaires or clinical examination to detect shoulder pain and infer shoulder problems (for example, [7,8,13]). Other studies inferred subacromial impingement from the biomechanical analysis of shoulder movement [19,29], or from clinical imaging techniques (such as MRI; [10]). There can be a problem comparing studies using shoulder pain to identify shoulder problems and studies inferring potential shoulder problems from biomechanical impingement or clinical imaging techniques. Sein et al [10] combined both subjective questionnaires with clinical examination and MRI assessment. They found a strong correlation between impingement sign and MRI-determined supraspinatus tendinopathy but showed some inconsistency when correlating supraspinatus tendinopathy with shoulder pain. Other studies have also found that using MRI does not always clearly identify shoulder pathology [30,31]. This suggests care is needed when interpreting evidence from MRI studies and all indicators of shoulder problems should be considered together.

3. Results and Discussion

The literature review found several factors that were associated with shoulder problems in swimmers. These were split into groups for ease of analysis and discussion. Calculating the effect size for each factor and its impact on shoulder problems allowed a list of those factors with the greatest impact on shoulder problems to be identified (Figure 1). Each group of factors will be discussed in turn. The effect size values for each factor, along with the range from the literature review are presented in Table 2. The subject characteristics from each study and the individual effect size values from each study included in this review are presented in Appendices 1-7.

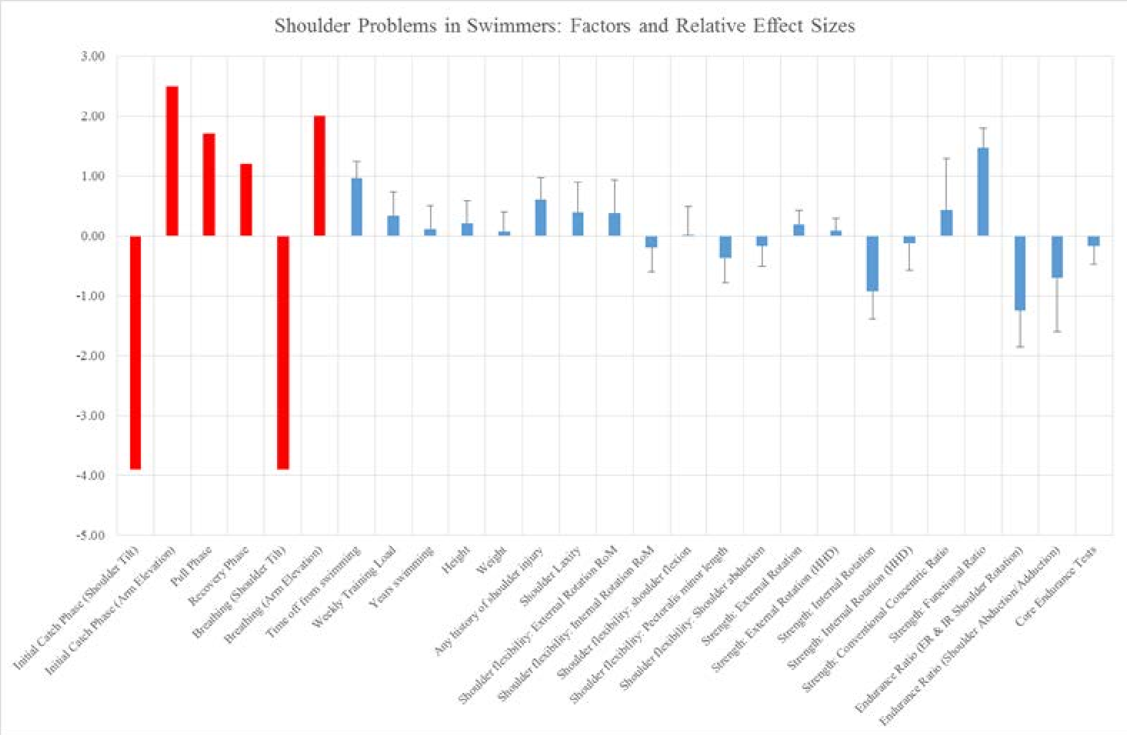

Figure 1. Effect sizes (mean and SD) of all the factors associated with shoulder problems from this review

Factors associated with shoulder pain are in blue and those associated with shoulder impingement are in red.

Table 2. Summary of effect sizes (Cohen's *d*) from factors related to shoulder problems in swimmers.

Shoulder Problems in Swimmers: Factors and Relative Effect Sizes	Subjective pain/ Impingement/ MRI	ES (Mean)	Min ES	Max ES	# Studies
Biomechanics: Initial Catch Phase (Shoulder Tilt)	Impingement	-3.90	-3.9	-3.9	1
Biomechanics: Initial Catch Phase (Arm Elevation)	Impingement	2.50	2.5	2.5	1
Biomechanics: Pull Phase	Impingement	1.70	1.7	1.7	1
Biomechanics: Recovery Phase	Impingement	1.20	1.2	1.2	1
Biomechanics: Breathing (Shoulder Tilt)	Impingement	-3.90	-3.9	-3.9	1
Biomechanics: Breathing (Arm Elevation)	Impingement	2.00	2	2	1
Time off from competitive swimming	Pain	0.97	0.78	1.16	1
Weekly Training Load (hr/week or m/week)	Pain/MRI	0.34	-0.31	0.85	4
Years swimming	Pain	0.12	-0.65	0.75	6
Height	Pain	0.22	-0.38	0.68	2
Weight	Pain	0.08	-0.41	0.61	2
Any history of shoulder injury	Pain	0.61	0.28	1.34	3
Shoulder Laxity	Pain	0.40	0.1	0.98	2
Shoulder flexibility: External Rotation RoM	Pain	0.38	-0.19	1.97	6
Shoulder flexibility: Internal Rotation RoM	Pain	-0.20	-1.03	0.46	5
Shoulder flexion (Active & Passive)	Pain	0.01	-0.9	0.61	2
Shoulder flexibility: Pectoralis minor length (rest & stretched)	Pain	-0.37	-1.14	0.1	2
Shoulder flexibility: Abduction (Horizontal & Neutral)	Pain	-0.17	-0.56	0.24	1
Strength: External Rotation (Concentric & Eccentric)	Pain	0.19	-0.11	0.45	1
Strength: External Rotation (HHD)	Pain	0.09	0	0.51	2
Strength: Internal Rotation (Concentric & Eccentric)	Pain	-0.92	-1.5	-0.49	1
Strength: Internal Rotation (HHD)	Pain	-0.13	-1.02	0.26	2
Strength: Conventional Concentric ER:IR Ratio	Pain	0.43	-0.24	1.66	2
Strength: Functional (Eccentric:Concentric) Ratio	Pain	1.47	1.24	1.7	1
Endurance Ratio (ER & IR Shoulder Rotation)	Pain	-1.25	-1.91	-0.49	1
Endurance Ratio (Shoulder Abduction & Adduction)	Pain	-0.71	-1.62	0.14	1
Core Endurance Tests	Pain	-0.17	-0.57	0.37	2

ES: Effect Size. For full results see Appendices 1-7.

3.1. Biomechanics of the Shoulder

Swimmers spend a considerable amount of time developing an efficient and effective swimming stroke. Several studies have discussed the biomechanics of the swimming action [11,15,20,23,32,33]. However, only Yanai and Hay [19] divided the frontcrawl swimming stroke down into three phases (catch, pull, recovery) to study the biomechanics of shoulder movement and provided results in a form that allowed calculation of effect sizes for the association of biomechanical movements and shoulder problems. Biomechanical factors come out as having the highest association to shoulder problems of all the factors found in this review (Figure 1; Table 2). However Yanai and Hay [19] used impingement inferred from biomechanical analysis rather than shoulder pain. If one of the major causes of shoulder problems in swimmers is impingement of the subacromial structures [15], identifying shoulder movements that result in impingement in swimmers is perhaps a good place to start when identifying factors associated with shoulder problems.

Shoulder pain and risk of shoulder impingement in swimming is most commonly experienced in the first half of the pull phase or the first half of the recovery phase of the swimming stroke [15,19]. During these phases, the position of the humerus is critical to any potential impingement. Yanai and Hay [19] and Yanai et al. [29] identified that, on average, 10.1% of the initial catch phase of the stroke and 10.4% of the recovery phase was spent in a position of impingement. In the catch phase, however, the muscular load placed on the shoulder will be much greater due to initiating the pull phase of the stroke cycle. This would suggest this phase of the stroke is a key area for the development of impingement and potential shoulder problems.

Yanai and Hay [19] showed that during the initial catch phase, there was a strong association between the maximum shoulder elevation angle and the amount of impingement (effect size = 2.5; Figure 1; Table 2). This means the higher the position of the hand relative to the head at the point of the initial catch in frontcrawl, the greater the potential for shoulder impingement. One way to reduce the risk of shoulder impingement here is to reduce the elevation angle at hand entry [19], perhaps by not stretching out as far forward for the catch or adopting a greater downward water entry angle of the hand, so the catch and pull phase starts with the hand lower in the water. However, this may compromise the propulsion generated from the catch at the start of the frontcrawl stroke. The hand position at entry can also contribute to shoulder problems [32]. The hand entering the water lateral to the shoulder or across the midline of the body can result in increased impingement at the shoulder.

Another strategy to reduce impingement in the catch phase may be to raise the level of the shoulder relative to the hand position at the catch. A common feature of successful frontcrawl swimmers is a high body position in the water. Indeed, some swimmers can even appear to swim with a ‘dry back’ due to their high body position. This would reduce the elevation angle at hand entry and catch, and therefore reduce the risk of impingement. This reasoning can be extended to what happens to the body position in the water as the swimmer becomes fatigued. Typically, as a swimmer becomes fatigued in competition or in training, they will swim lower in the water. Their shoulders and upper body will not be as elevated but the position of the hand at entry/catch may not change. This will allow the swimmer to maintain their catch and length of stroke but the elevation angle of the shoulder, and risk of impingement, will therefore increase. Fatigue is one of the main factors thought to be associated with shoulder problems in swimmers [20,22] and the subsequent change in body position and arm elevation angle may be a significant part of this.

The shoulder TILT angle is the rotation of the shoulder girdle about the frontal axis of the trunk (sometimes described as shoulder roll). The TILT angle of the shoulders showed a very strong negative association with risk of shoulder impingement, meaning greater TILT angle resulted in less shoulder impingement (effect size = -3.9; Table 2). A flat frontcrawl stroke with little shoulder roll, besides making efficient breathing difficult, places the shoulders at risk of impingement. The elevation angle necessary to reach a given arm orientation relative to the trunk is reduced if the TILT angle is increased [19]. This can be achieved by side bending of the trunk (which would create a detrimental snake-like effect in the water) or by greater body roll. The ideal front crawl stroke has a body roll of approximately 45˚ along the longitudinal axis of the body [32]. A lack of body roll increases the mechanical stress placed on the shoulder and excessive body roll can result in humeral hyperextension if the swimmer maintains optimal pull-through mechanics [15,32]. Correct body roll can also have a beneficial impact on risk of shoulder impingement during the recovery phase of the stroke (discussed later).

The least impingement typically occurs during the pull phase of the frontcrawl stroke [19]. During this phase of the stroke, the main risk factor of shoulder impingement was the internal rotation of the arm (effect size = 1.7; Table 2). A greater internal rotation angle of the arm results in a greater risk of shoulder impingement. It is during this phase that the dropped elbow - a common fault in frontcrawl stroke biomechanics - occurs. The dropped elbow results in a mechanical disadvantage in the frontcrawl stroke [34], but the high elbow, whilst being mechanically advantageous to generate propulsion, increases the internal rotation angle of the arm and places the shoulder at risk of impingement [19]. The best solution to this dilemma seems to be to increase the strength of the shoulder muscles [19] - an approach that will benefit all phases of the swimming stroke. A similar situation to this has been seen in other swim strokes. In butterfly, to minimise shoulder stress and maximise mechanical advantage, a downward hand entry angle will create a strong arm position with the hands below the level of the shoulders ready to start elbow flexion and the propulsive phase of the stroke [33].

Shoulder impingement is equally prevalent in the initial catch and recovery phases of the frontcrawl swimming stroke [19]. During the recovery phase, greater arm internal rotation was associated with greater risk of shoulder impingement (effect size = 1.2; Table 2). The largest internal rotation angles occur when the swimmer adopts a high elbow recovery, and/or when the elbow leads the wrist during the early recovery. A limited range of motion in internal rotation in swimmers may also increase the risk of shoulder impingement – this is further discussed under the heading Shoulder Laxity and Range of Movement. Arm recovery with a higher hand position and a reduction in the time the hand is behind the elbow, to reduce the internal rotation angle of the arm, will reduce impingement risk during recovery. This also suggests some commonly used frontcrawl technique drills which keep a lower hand position, such as trailing fingers in the water during recovery, and touching the hips and shoulder during recovery will place the shoulder at risk of impingement.

Breathing is another area that can impact on risk of shoulder impingement. Swimmers who breathe predominantly to one side are more likely to develop shoulder problems on their breathing side than on the other side [19]. Similar to the initial catch phase of the stroke, the breathing action resulted in a greater shoulder TILT angle on the non-breathing side than the breathing side, and as discussed above, this strongly reduces the risk of impingement on that shoulder (effect size = -3.9; Table 2). This then also reduces the elevation angle of the arm on the non-breathing side, also reducing the risk of shoulder impingement (effect size = 2.0; Table 2). Developing bilateral breathing will then help develop a balanced frontcrawl stroke and reduce the risk of shoulder problems.

3.1.1. Summary: Biomechanics of the Shoulder

Frontcrawl stroke biomechanics show the greatest association to shoulder impingement of all the factors studied in this paper (Figure 1), by virtue of the largest effect size values (impingement inferred from analysis of shoulder movement during the swimming stroke, rather than from subject-reported shoulder pain). All the biomechanical characteristics showed a very large effect size on shoulder impingement. Shoulder impingement occurred predominantly in the initial catch phase and the recovery phases of the frontcrawl stroke. The predominant breathing side also influenced shoulder impingement:

- Initial Catch Phase: smaller shoulder TILT angle (shoulder roll) and larger arm elevation angles (lower shoulders relative to hand entry) increased shoulder impingement (effect size = -3.9 and 2.5 respectively);
- Recovery Phase: greater arm internal rotation resulted in greater shoulder impingement (effect size = 1.2);
- Breathing: smaller shoulder TILT angle and larger arm elevation angles increased shoulder impingement (effect size = -3.9 and 2.0 respectively).

However, only one study was used in the analysis [19], as it was the only study to provide results in a form that allowed calculation of effect sizes. More studies in this area would help confirm the above results.

3.2. General Swimmer Characteristics

General swimmer characteristics included the anthropometric characteristics of the swimmers, the length of time the swimmer has been competing, the training load, and whether they had taken a break in their swimming career at any point. Six suitable studies were found with results in a form that allowed the calculation of effect size scores [7,10,12,13,14,35]; see Appendix 3) and a summary of these results is presented in Figure 1 and Table 2.

Swimmers who took time off from swimming had a moderate-to-strong association with developing shoulder problems (effect size = 0.97; Table 2). Swimmers spend a considerable amount of time training for their sport, and breaks in this cumulative adaptation may lead to disuse, resulting in atrophy or altered neuromuscular control of the stabilizing shoulder girdle musculature [22]. This will increase the chance of shoulder injuries upon return to the high volume of training associated with competitive swimming, as athletes attempt to make up for lost time or do not allow for the disuse effect. No information is given regarding the reasons for the subjects taking a break, such as previous injury or school exam pressure for example, but it suggests balancing swim training in the daily routine may be more beneficial than taking a break with the aim of returning to competitive swimming later.

The number of years spent in competitive swimming did not show a consistent effect on shoulder problems (average effect size = 0.12; Table 2). The weekly training load (hours/week, or m/week) also had no clear association with shoulder problems (Table 2). However, Sein et al [10] showed an increasing incidence of MRI-identified supraspinatus tendinopathy with training load, leading to a complete incidence of supraspinatus tendinopathy in all swimmers swimming more than 20 hours a week or more than 60000m/week. However only inconsistent evidence of an association of these MRI results with subjective shoulder pain was observed.

Body height showed an interesting relationship to shoulder problems. In younger swimmers, Tate et al [13] showed an increase in shoulder pain, dissatisfaction and disability (PDD) with an increase in height in 8-11 year olds and 12-14 year old female swimmers (mean effect size across 8-14 year olds is 0.60; Appendix 3). This may suggest younger, taller swimmers develop a biomechanically unfavourable stroke which perhaps improves and becomes less of a risk factor as they get older and stronger. Overall, the association between height and shoulder problems is not consistent (effect size = 0.22; Table 2). Body weight also shows no clear association with shoulder problems (effect size = 0.08; Table 2), but is higher in 12-14 year old female swimmers (effect size = 0.61, Appendix 3). The tentative conclusion from the small number of studies is that care should be taken with taller, younger athletes (under 14 years) but the relationship is less clear in older athletes.

3.2.1. Summary: Shoulder Problems and General Swimmer Characteristics

The main general swimmer characteristics associated with shoulder problems are:

- Swimming more than 20 hours/week or 60000m/week (incidence of MRI-assessed supraspinatus tendinopathy);
- Taking time off from swimming (mean effect size = 0.92);
- Increased height in swimmers under 14 years of age (mean effect size = 0.60).

3.3. Injury History

Previous injury is commonly the biggest predictor of subsequent injury and can become a significant barrier to maintaining a healthy active lifestyle [8,36,37,38,39]. Three studies showed the relationship between injury history and shoulder problems and provided their results in a form that allowed calculation of effect sizes (Table 4) [7,8,25]. A history of injuries in swimming had a moderate association with subsequent shoulder problems (effect size = 0.61; Table 2). In a prospective study over 12 months, Walker et al. [8] also observed that swimmers with more serious shoulder injuries were more likely to have had a previous shoulder injury, compared to swimmers with less serious shoulder injuries (Appendix 4). This suggests considerable effort is needed to avoid shoulder problems in the first place, or once injured, extra focus needs to be placed on rehabilitation of swimmers to avoid developing a more serious injury. This implies that rehabilitation processes are often inadequate to avoid injury recurrence [39].

3.3.1. Summary: Injury History

Injury history and therefore rehabilitation are important factors for shoulder problems in swimmers:

- Previous injury is a moderate predictor of subsequent injury (overall mean effect size = 0.61).
- Effective rehabilitation is important to avoid recurrence and progression of shoulder problems.

3.4. Shoulder Laxity and Range of Movement

Much focus has been placed on the relationship between shoulder laxity, shoulder flexibility/range of movement and shoulder problems in swimmers. Range of movement tests can be regarded as crude indicators of joint laxity but can show some significant differences and do not necessarily reflect ligamentous laxity [40]. Shoulder laxity is typically assessed from anterior and posterior translation of the humeral head in the shoulder capsule [40]. Shoulder flexibility/range of movement is typically assessed from more active arm and shoulder movements such as external and internal shoulder rotation, shoulder flexion, extension, abduction and adduction [41]. Shoulder laxity and shoulder flexibility are two parameters that can be related but may have different associations with shoulder injury. This review will consider shoulder laxity and shoulder flexibility/range of movement separately.

3.4.1. Shoulder Laxity

The glenohumeral joint is a highly mobile joint and is balanced in the shoulder complex by the stability of the acromioclavicular and sternoclavicular joints [22] and supported by the shoulder musculature. The shoulder joint provides about 90% of the propulsive force in frontcrawl swimming [42] and a stable joint is essential for proper frontcrawl stroke mechanics [43]. Swimmers typically show increased shoulder laxity [40,43], although this is not always unequivocal [44], and whether this increased laxity is acquired or inherent is a matter of debate [40,45]. Increased shoulder laxity can be both advantageous to swimmers [15], and be associated with shoulder problems [40,43,45,46]. Overall, shoulder laxity showed a small association with shoulder problems (effect size = 0.40; Table 2), although there was quite a wide range in the results from the two studies. The older paper [43] showed a strong association between Shoulder Laxity Clinical Examination score and shoulder problems (effect size = 0.1). However, a more recent study using a different technique [6] found little difference in shoulder laxity between painful and pain-free shoulders. Any increased laxity can be potentially compensated by the supporting effect of the stabilising muscles of the shoulder to avoid potential impingement [19,44,45]. Fatigue of the shoulder muscles may then have a significant impact on potential shoulder problems, when the stabilising effect of the shoulder muscles is reduced. The association of shoulder strength and shoulder problems is further discussed under the heading Shoulder Strength. It is also worth bearing in mind that the process of assessment of shoulder laxity can present significant methodological challenges due to the subjective nature of many of the techniques used (discussed in [6,8,10]. More recent studies [6,10] have used newer, quantitative methods of analysis of shoulder laxity. The results from more recent studies and overall lack of consistent results from the studies of shoulder laxity in swimmers suggest it is not a major predictor of shoulder problems.

3.4.2. Shoulder Flexibility/Range of Movement

Swimmers have typically shown an increased shoulder range of movement, with excessive external rotation and limited internal rotation [41,47]. We found six studies that investigated the relationship between shoulder flexibility/range of movement and shoulder problems [8,12,13,41,47,48], with results in a form we could include in this review (Table 2). Increased shoulder external rotation had a moderate association with increased shoulder problems (mean effect size = 0.38; Table 2), and increased internal rotation of the shoulder had a small mean association with reduced shoulder problems (mean effect size = -0.20) but with a wide range of effect sizes (range: -1.03 to 0.46; Table 2). Biomechanical analysis of the frontcrawl swimming stroke suggests that adequate shoulder rotational range of movement is necessary for correct and efficient swimming technique [19,29]. Blanch [23] states that adequate internal rotation of the glenohumeral joint allows swimmers to be able to achieve and maintain an early catch and high elbow throughout the stroke. The points of shoulder impingement in the frontcrawl stroke - the catch and the recovery - do seem to be initiated by internal rotation of the shoulder. Perhaps the small association in our findings of the internal shoulder rotation ability and shoulder problems suggests that correct stroke biomechanics and adequate shoulder strength are more important than internal shoulder rotation, and that without a correct stroke, a swimmer would be at risk of shoulder problems regardless of their internal shoulder rotation ability.

Other measures of shoulder flexibility may be useful here. As mentioned earlier, swimmers typically have limited internal shoulder rotation range of movement. Tightness in the posterior shoulder capsule will limit this internal rotation, and indeed internal rotation is often used as an indicator of posterior joint tightness [23]. Changing the plane of the scapula will also impact on the type of motion at the shoulder joint [23]. A reduced pectoralis minor length can potentially adversely alter scapular mechanics. Increased length of pectoralis minor, both at rest and when stretched, was associated with a small to moderate reduction in shoulder problems (effect size = -0.37; Table 2). The slightly increased pectoralis minor length will allow the scapula greater opportunity to move optimally. Scapula control and changes in scapula position itself has been shown to influence the subacromial space [49,50]. Adequate shoulder flexibility may be important for swimmers to achieve an efficient and effective stroke, but increased shoulder flexibility and range of movement may only be related to shoulder problems if the shoulder musculature cannot control the increased shoulder movement.

The results suggest that a lack of basic flexibility does not associate strongly with shoulder problems. This is perhaps partly due to the studies included in Table 2 investigating the association of shoulder flexibility and shoulder problems using experienced swimmers as their subjects, typically aged between 15-19, swimming an average of 12 hours (range: 4-18.8 hours) or 42km (range: 9-110km) per week. Individuals who had limited flexibility may be unlikely to be included in these studies as they would not be swimming at these levels. All this tends to suggest that whilst swimmers may typically have greater external shoulder rotation RoM, reduced internal shoulder rotation RoM and greater shoulder laxity these parameters do not clearly predict swimmers who are at risk of shoulder injury.

3.4.3. Summary: Shoulder Laxity and Range of Movement

The results presented in the meta-analysis suggest shoulder laxity and shoulder flexibility/range of movement are not major factors in shoulder problems in swimmers. Some factors may have a small association to the shoulder problems experienced by swimmers:

- Adequate basic shoulder range of movement is important to allow efficient and effective swimming;
- The majority of swimmers in these studies are likely to have a good, basic range of shoulder movement to allow them to train for an average 12 hours (range: 4-18.8 hours) or 42km (range: 9-110km) per week;
- Shoulder laxity does not seem to be associated with shoulder problems in swimmers;
- Increased internal shoulder rotation has a small association with a reduction in shoulder problems (effect size = -0.25). Pectoralis minor length can also influence scapula position, and has a moderate association with reduced shoulder problems (mean effect size = -0.37);
- Increased external shoulder rotation has a small to moderate association with developing shoulder problems (mean effect size = 0.42);
- Some stretching programs may be harmful to the capsuligamentous structures of the shoulder;
- Having adequate support for the glenohumeral joint from the shoulder musculature during the swimming motion is important. Any small differences in shoulder laxity and shoulder flexibility/range of movement can then be compensated for by a strong shoulder musculature.

3.5. Shoulder Strength

Several of the studies investigating Shoulder Laxity and Range of Movement also looked at measures of shoulder strength and muscle function. We found four studies that used a variety of measures of strength and muscle function to investigate shoulder strength and its association with shoulder problems, with results in a form that allowed calculation of effect sizes (Table 2) [12,13,41,47].

Two main methods have been used in the literature to assess muscle strength. Harrington et al. [12], Tate et al. [13] and Bak and Magnusson [47] used a hand held dynamometer (HHD) to assess a variety of isometric strength scores of their subjects. Additionally, Bak and Magnusson [47] along with Beach et al. [41] used isokinetic dynamometers to measure the concentric and eccentric isokinetic strength for shoulder internal and external rotation. These two techniques of measurement showed broadly similar general trends when associating internal and external shoulder rotation strength and shoulder problems (Table 2), and the two techniques have been shown to be comparable [51,52]. However the HHD device seemed to be less sensitive to detecting shoulder problems from changes in shoulder strength compared to the isokinetic devices (compare effect size values in Table 2). All the studies using the HHD devices found little significant difference in strength measurements from those with and without shoulder problems [12,13,47]. Whilst the results from the two methods of measurement are broadly in agreement, due to the lack of a significant association with shoulder problems when using the HHD device we will use results from the more established isokinetic methods of strength measurement in this discussion.

Overall, increased isokinetic internal shoulder rotation strength (both concentric and eccentric) showed a much greater association with reduced shoulder problems (effect size = -0.92) than concentric and eccentric external shoulder rotation strength (effect size = 0.19; Table 2). This is consistent with the small association of increased internal shoulder rotation RoM with a reduction in shoulder problems discussed under the heading Shoulder Laxity and Range of Movement (Table 2), but internal rotation shoulder strength appears to have a much greater impact.

Agonist:antagonist muscle strength ratios are often used to identify weakness in particular muscles, give information on the muscular strength and power balance, and inform a strength and conditioning programme [47,53,54]. Bak and Magnusson [47] and Beach et al. [41] went on to calculate agonist:antagonist muscle strength ratios in swimmers. The conventional concentric isokinetic shoulder strength ratio (concentric external shoulder rotation strength: concentric internal shoulder rotation strength) showed a moderate association with shoulder problems (effect size = 0.43; Table 2). This was largely due to the differences in internal rotation strength, as there was little change in the external shoulder rotation strength values between groups with and without shoulder problems (Appendix 6). These concentric isokinetic strength ratios also appear to be less sensitive to shoulder problems than the simple internal shoulder rotation strength scores (mean effect size = -0.92; Table 2).

Swimmers tend to develop lower conventional isokinetic strength ratios (concentric external rotation: concentric internal rotation) largely due to strong concentric internal rotation strength. Whether this imbalance is associated with shoulder injury or is a normal adaptation to the performance demands of the sport is not clear. However, during ballistic overhead movement eccentric activity of the shoulder external rotators is used to decelerate the humerus and prevent impingement [47]. The functional isokinetic shoulder strength ratio (eccentric external shoulder rotator strength: concentric internal shoulder rotator strength) is then perhaps more closely aligned to the shoulder actions of overhead sports [47,55,56] and may be appropriate for analysing the swimmers' shoulder. However, Bak and Magnusson [47] found a strong association between increased functional isokinetic shoulder strength ratio and an increase in shoulder problems in swimmers (effect size = 1.47; Table 2).

In the frontcrawl swimming action the points of potential shoulder impingement - the catch and the recovery - are initiated by internal rotation of the shoulder. To avoid the impingement of the humerus onto the subacromial structures this concentric internal shoulder rotation action needs to be stabilised by strong eccentric external rotator muscle activity. This will decelerate and cause an inferior and posterior translation of the humeral head thus minimising potential impingement. It may then be desirable for the functional isokinetic strength ratio to rise above 1.0 in overhead athletes, to reflect greater eccentric external shoulder rotation strength. Scoville et al. [55] measured functional isokinetic strength ratios in overhead athletes of over 1.0, and Noffall [56] showed functional isokinetic strength ratios over 1.0 in throwing athletes. However, in uninjured swimmers Bak and Magnusson [47] showed a functional isokinetic strength ratio of 0.86. This apparent discrepancy may be partly due to the speed of isokinetic testing. As isokinetic speed increases, concentric force will decrease and eccentric force with remain the same or increase. So as the speed of testing increases, the functional isokinetic strength ratio will increase [55,56]. Noffall [56] used isokinetic testing speeds of 300 degrees/sec and Scoville et al [55] used 90 degree/sec. However, Bak and Magnusson [47] used 30 degree/sec (swimming muscle contraction speeds are estimated to be approximately 80 degrees/sec; [47,57]. This would reduce the magnitude of the contribution from the muscles' elastic elements, reducing the eccentric contribution to muscle contraction. The concentric internal rotation strength is also part of the functional ratio, and Bak and Magnusson [47] showed a fall in concentric internal rotation strength in swimmers with shoulder problems. The speed of testing and the reduced concentric internal rotation strength together may account for the large association of functional shoulder strength ratio and shoulder problems. Eccentric external muscle contraction strength seems useful in theory. However, the single study that has investigated this in swimmers did not show a clear benefit but did suggest that the functional strength ratio seemed slightly more sensitive at detecting differences in shoulder rotation strength than the conventional strength ratios. Further studies using functional strength ratios in swimmers would help to clarify this.

Beach et al. [41] then went on to investigate shoulder muscle endurance from the decline in peak torque over 50 repetitions of shoulder internal, external, abduction and adduction exercises (Table 2). Greater internal and external shoulder rotation endurance showed a very large association with reduced shoulder problems (effect size = -1.25; Table 2). Greater shoulder abduction and adduction endurance also had a large association with reduced shoulder problems (effect size = -0.71; Table 2). Fatigue from swim practice has also been shown to reduce scapula movement and scapula control only in swimmers with shoulder impingement [50]. This supports the assertion of the important role of the shoulder musculature and conditioning in supporting the shoulder and that fatigue is a key parameter in the incidence of shoulder problems.

3.5.1. Summary: Shoulder Strength

- Isokinetic measures of shoulder strength show a much greater association with reduced shoulder problems than isometric measures of shoulder strength;
- Concentric and eccentric internal rotation strength appear to be important in protecting against shoulder problems (effect size = -0.92; Table 2);
- The balance of the concentric external and internal rotation strength (conventional shoulder strength ratio) may be important to prevent shoulder problems, largely due to differences in internal rotation strength (effect size = 0.43; Table 2); Greater eccentric external shoulder rotator muscle strength in swimmers, and the functional isokinetic strength ratio seem useful in theory, but there is no clear experimental evidence;
- Muscle endurance values from internal and external shoulder rotation, and shoulder abduction and adduction showed a strong association with shoulder problems, reinforcing the important role of the shoulder muscles and conditioning in supporting the shoulder joint.

To our knowledge, only one study has investigated the functional ER:IR strength ratio in swimmers, and only one study has investigated the endurance properties of the shoulder muscles in swimmers. This limits the conclusions that can be made and more studies in this area would be beneficial.

3.6. General Strength

The main propulsive force for frontcrawl swimming comes from the arms and shoulders [42]. The important role of the shoulder musculature to support the shoulder joint has been discussed above. However, swimming is a whole body activity and the body is a series of interconnected joints and all are involved in coordinating an effective, efficient swimming stroke. Many of the studies that looked specifically at shoulder strength also looked at whole body strength and its association to shoulder problems. We found two such studies that investigated general, whole body strength and its association with shoulder problems, with results in a form that allowed calculation of effect sizes [12,13].

Weakness in any area of the body may place extra stress on the shoulder joint and may result in increased injury risk. The two studies summarised in Table 2 focused on common tests of core stability: side-bridge, prone-bridge, and a functional test of the upper body kinetic chain (the closed kinetic chain upper extremity stability test). All the general strength tests produced low associations with shoulder problems, suggesting little direct association with core stability strength. Tate et al. [13] did however find a trend in 12-14 year old female swimmers for reduced core strength scores to be associated with increased shoulder problems (mean general strength effect size from 12-14 year old female swimmers = -0.52 compared to mean from female swimmers aged 15 and over = -0.15; Appendix 7). This may be associated with the rapid developmental changes that occur in adolescents at this age and is consistent with the observation regarding height in the same age group discussed under the heading General Swimmer Characteristics, and it reinforces the tentative conclusion that care should be taken with taller, younger athletes (under 14 years). Any rapid growth at this age may predispose the swimmer to shoulder injury as the changes in the body size place the stroke at a biomechanical disadvantage and greater injury risk. It supports the concept of all round fitness and conditioning and the importance of cross training, particularly with this age group [13]. By developing good basic foundations of movement and frontcrawl stroke mechanics, swimming efficiency will improve and the risk for future injury will be reduced.

3.6.1. Summary: General Strength

The two studies that investigated the association of general strength to shoulder problems suggested:

- There is little association between measures of general core stability endurance and shoulder problems;
- There is a suggestion that general core stability strength to be associated with shoulder problems in 12-14 year old adolescent females. This perhaps reflects the rapid development changes that can occur in adolescent swimmers that may perhaps place the body at biomechanical disadvantage during the frontcrawl stroke. This study [13] only used female subjects but there is no reason why this interpretation cannot also apply to male adolescent swimmers.

Conclusions from only two studies are however limited, and more studies allowing comparison would be beneficial.

4. Conclusion

4.1. Swimmers and Shoulder Problems

One of the major causes of shoulder problems in swimmers has been suggested to be impingement of the subacromial structures [15]. Strategies to reduce or avoid shoulder problems should then focus on factors that increase the risk of shoulder impingement. The shoulder joint provides about 90% of the propulsive force in frontcrawl swimming [42], and frontcrawl is the predominant stroke used by high level competitive swimmers, even if it is not their best or preferred stroke [8,20]. Swimmers can perform up to 44000 shoulder rotations each week, so unsurprisingly the shoulder is the most common point of injury in swimmers [8]. This review focussed on frontcrawl and the risk factors associated with shoulder injuries in this stroke.

We used the term shoulder problems in this summary as the studies used in this review used two methods of identifying shoulder problems in swimmers: presence/history of shoulder pain and presence of shoulder impingement. This was illustrated by the results investigating the association of weekly swim duration and weekly swim distance to shoulder problems. The amount of time spent swimming or distance completed each week showed a clear relationship to supraspinatus tendinopathy (present in all swimmers swimming more than 20 hours or 60km per week; [10], but only a small to moderate association with shoulder pain (effect size = 0.34; Table 2). Shoulder pain and clinical shoulder impingement are not necessarily the same thing. Shoulder impingement may be a less symptomatic version of shoulder pain. Sein et al. [10] combined both subjective questionnaires with clinical examination and MRI assessment. They found a strong correlation between impingement sign and MRI-determined supraspinatus tendinopathy but the relationship was less clear when correlating shoulder pain with supraspinatus tendinopathy. If one assumes that all shoulder pain is caused by shoulder impingement, but not all shoulder impingement may show signs of shoulder pain, then the effect size of studies investigating shoulder impingement will be a little higher than those investigating shoulder pain. Nevertheless, it seems swimmers routinely swimming over 15 hours or 35km a week have a greater risk of shoulder problems.

This study found six main factors that associated with shoulder problems: biomechanical factors (stroke technique); general swimmer characteristics; injury history; shoulder laxity and range of movement; shoulder strength; and general strength. All the risk factor groups will of course, be interrelated to some degree. For example, fatigue and reduced muscular endurance can reduce the ability of the shoulder muscles to support the shoulder, and fatigue can also change the body position in the water, potentially changing the biomechanics of the swimming stroke. Injury history can be related to underlying shoulder strength or muscle endurance, and an imbalance in shoulder strength may predispose one shoulder to injury. However, the current review suggested that the biomechanics of the swim technique was perhaps more important in predicting shoulder problems.

There was a suggestion that the anthropomorphic changes associated with puberty may increase the risk of developing shoulder problems. The rapid development changes that can occur at this age may contribute to a changed stroke technique that may increase the risk of shoulder problems. It reiterates the importance of an effective, efficient frontcrawl stroke, and suggests that extra attention should be paid to swimmers in these age groups.

The results of this review suggest that shoulder RoM and shoulder laxity do not show a clear association with shoulder problems. This may sound surprising but may be partly due to the subject groups used in the majority of studies used in this review. The majority of swimmers in these studies are likely to have a good, basic range of shoulder movement to allow them to practice in the water for an average of 12 hours (range: 4-18.8 hours) or 42km (range: 9-110km) per week. This may influence the results to some extent. Shoulder movements or muscles that were associated with shoulder problems were also highlighted. These can form key activities in any strength and conditioning program or rehabilitation program alongside water-based swim training.

Statement of Competing Interests

The authors have no competing interests.

Abbreviations

ES: Effect Size
HHD: Hand Held Dynamometer
MRI: Magnetic Resonance Imaging
PDD: Pain, Disatisfaction and Disability
SIS: Subacromial Impingement Symdrome
SPS: Subacromial Pain Symdrome

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Appendix 1. Subject Characteristics of the Studies Used

Reference	Subject Gender (number)	Subject Age: yrs (SD)	Subject Height (cm)	Subject Weight (kg)	Shoulder Injuries (%)	Swim Load	Level
Chase et al. (2013)	M (16); F (18)	M: 19.6; F: 19.3	M: 183.7; F: 168.6	M: 80.1; F: 64.9		25558 m/week	Collegiate
Tate et al. (2012)	F (236)	8-11yr (n=42); 12-14yr (n=43); 15-19yr (n=84); 23-77yr (n=67)	146.8 (9.0); 162.2 (10.6); 166.1 (6.4); 167.6 (6.9)	36.4 (7.2); 50.8 (6.9); 58.5 (8.2); 66.1 (11.5)	21.4; 18.6; 22.6; 19.4	(hr/week) 6.9 (2.4); 10.1 (4.3); 16.1 (6.0); 4.0 (1.7);	Youth; Youth; High School; Masters
Abgarov et al. (2012)	M (78); F (92)	21.0 (1.76)			70		Collegiate
Harrington et al. (2014)	F (37)	19.5 (1.19)	170 (7)	64.7 (6.8)	35.1	18.8 hrs/week	Collegiate
Sein et al. (2010)	M (42); F (38)	15.9 (2.7)			91	median values: 16 hours/week (8-29hr); 40km/week (9-110km)	Club to International
Mohseni-Bandpei et al. (2010)	M (45); F (36)	23.47 (4.88)	172.62 (9.83)	68.49 (11.24)	29.6		Collegiate
Walker et al. (2012)	M (37); F (37)	M: 16 (± 3); F: 15 (± 3)	M: 175 (± 14); F: 166 (± 6)			(m/week) M: 46000 (± 15000); F: 43000 (± 15000)	State, National, International
Yanai and Hay (2000)	M (11)						Collegiate
Bak and Magnusson (1997)	M (9); F (6)	18.5 (15-25)				32933 (356) m/week	National
Beach et al. (1992)	M (8); F (24)	19			69	51206m/wk	Collegiate
McMaster et al. (1998)	M (27): F (13)	17.5 (2.4)			35		National, International
Borsa et al. (2005)	M (26); F (16)	M: 19.4 (1.6); F: 19.7 (1.0)	M 187.9 (6.6); F: 170 (7.2)	M: 82.3 (6.2); F: 65.5 (4.5)	64	56693m/wk	Collegiate
Bansal et al. (2007)	M (161)	17-35			17.4		State to International

M: Male; F: Female.

Appendix 2. Summary of studies investigating the association of biomechanics factors and shoulder problems.

Reference	Subject Notes	Factor	Equivalent Effect Size (Cohen's d)
Yanai and Hay (2000)	M (11)	Initial Catch Phase: TILTmax vs. %ST	-3.9
		Initial Catch Phase: ELmax vs. %ST	2.5
		Pull Phase: IRpull vs. %ST	1.7
		Recovery Phase: IRrec vs. %ST	1.2
		Breathing Action: TILTmax vs. %ST	-3.9
		Breathing Action: ELmax vs. %ST	2

%ST: shoulder impingement as % of the total stroke time.

Appendix 3. Summary of studies investigating the association of general swimmer characteristics and shoulder problems

Reference	Subject Notes	Factor	Equivalent Effect Size (Cohen's d)
Chase et al. (2013)	Per 1000 hours exposure	Gender (vs. Female) (unadjusted IRR)	-0.02
		Gender (vs. Female) (adjusted IRR[1])	-0.14
		Years swimming (unadjusted IRR)	0.04
		Years swimming (adjusted IRR[1])	0.02
Chase et al. (2013)	Per 1000 athlete exposures	Gender (vs. Female) (unadjusted IRR)	-0.18
		Gender (vs. Female) (adjusted IRR[1])	-0.12
		Years swimming (unadjusted IRR)	0.04
		Years swimming (adjusted IRR[1])	0.02
Tate et al. (2012)	8-11yr (n=42)	Height (Positive vs. Negative Pain, Dissatisfaction and Disability)	0.52
	12-14yr (n=43)		0.68
	15-19yr (n=84)		0.16

	23-77yr (n=67)		0.22
	8-11yr (n=42)	Weight (Positive vs. Negative PDD)	0.03
	12-14yr (n=43)		0.61
	15-19yr (n=84)		0.1
	23-77yr (n=67)		0.12
	8-11yr (n=42)	BMI (Positive vs. Negative PDD)	-0.39
	12-14yr (n=43)		-0.23
	15-19yr (n=84)		0.06
	23-77yr (n=67)		0.03
	8-11yr (n=42)	Age (Positive vs. Negative PDD)	0.35
	12-14yr (n=43)		0.56
	15-19yr (n=84)		0.38
	23-77yr (n=67)		0.15
	8-11yr (n=42)	Time Swimming (yrs) (Positive vs. Negative PDD)	-0.12
	12-14yr (n=43)		0.43
	15-19yr (n=84)		0.56
	23-77yr (n=67)		0.48
	8-11yr (n=42)	Weekly Swim (hrs) (Positive vs. Negative PDD)	0.52
	12-14yr (n=43)		0.24
	15-19yr (n=84)		0.1
	23-77yr (n=67)		0.6
Abgarov et al. (2012)	M: 78; F: 92	Age started competitive swimming	-0.08
		Age started competitive swimming: Males	-0.12
		Age started competitive swimming: Females	-0.04
		Years in competitive swimming	-0.02
		Years in competitive swimming: Males	-0.06
		Years in competitive swimming: Females	0.01
		Time off from competitive swimming	0.82
		Time off from competitive swimming: Males	1.16
		Time off from competitive swimming: Females	0.78
Harrington et al. (2014)	F (37)	Dominant Arm: Age (positive vs. negative shoulder pain and disability)	0.05
		Dominant Arm: Height (positive vs. negative shoulder pain and disability)	0.09
		Dominant Arm: Weight (positive vs. negative shoulder pain and disability)	-0.41
		Dominant Arm: BMI (positive vs. negative shoulder pain and disability)	-0.51
		Dominant Arm: Years competing (positive vs. negative shoulder pain and disability)	-0.65
		Dominant Arm: Weekly swim Time (positive vs. negative shoulder pain and disability)	-0.31
		Non-Dominant Arm: Age (positive vs. negative shoulder pain and disability)	-0.15
		Non-Dominant Arm: Height (positive vs. negative shoulder pain and disability)	-0.38
		Non-Dominant Arm: Weight (positive vs. negative shoulder pain and disability)	0.03
		Non-Dominant Arm: BMI (positive vs. negative shoulder pain and disability)	0.39
		Non-Dominant Arm: Years competing (positive vs. negative shoulder pain and disability)	0.19
		Non-Dominant Arm: Weekly swim Time (positive vs. negative shoulder pain and disability)	-0.01

Sein et al. (2010)	M: 42; F: 38	Swim > 15 hours/week and supraspinitus tendinopathy	1.09
		Swim > 20 hours/week and supraspinitus tendinopathy	NA
		Swim distance and supraspinitus tendinopathy	0.70
		Swim >35km/week and supraspinitus tendinopathy	0.80
		Swim >60km/week and supraspinitus tendinopathy	NA
		Level of training and Impingement Pain	0.58
		Years of Swim Training and Impingement Pain	0.75
		Impingement Sign and Supraspinitus tendinopathy	1.12
Mohseni-Bandpei et al. (2010)	M: ~45; F: ~36	Male (vs. Female) and lifetime shoulder pain	0.43
		Age (<20 vs. >20) and lifetime shoulder pain	-0.04
		BMI (<20 vs. >20) and lifetime shoulder pain	-0.24
		Years of practice (<3 vs. >3) and lifetime shoulder pain	-0.24
		Level of Sport (National vs. Club/College) and lifetime shoulder pain	0.23
		WU duration (<15min vs. >15min) and lifetime shoulder pain	0.02
		Days practice/week (1-2 vs. >2) and lifetime shoulder pain	-0.15

[1]: Adjusted for other factors as appropriate (gender, years swimming, any injury history, and injury history to same anatomical location).

Appendix 4. Summary of studies investigating the association of injury history and shoulder problems.

Reference	Subject Notes	Factor	Equivalent Effect Size (Cohen's d)
Chase et al. (2013): Per 1000 hours exposure	M: 16; F: 18	Any history of injury (vs. no injury) (unadjusted IRR)	0.73
		Any history of injury (vs. no injury) (adjusted IRR)[1]	0.58
		History of injury to same anatomical location (unadjusted IRR)	0.49
		History of injury to same anatomical location (adjusted IRR)[1]	0.28
Chase et al. (2013): Per 1000 athlete exposures		Any history of injury (vs. no injury) (unadjusted IRR)	0.71
		Any history of injury (vs. no injury) (adjusted IRR)[1]	0.56
		History of injury to same anatomical location (unadjusted IRR)	0.50
		History of injury to same anatomical location (adjusted IRR)[1]	0.31
Walker et al. (2012)	M: 37; F: 37	Significant Shoulder Injury (SSI) adjusted for weekly swim distance: Past Injury History (vs. no injury history)	1.34
		Significant Interfering Shoulder Pain (SIP) adjusted for weekly swim distance: Past Injury History (vs. no injury history)	0.78
Abgarov et al. (2012)	M: 78; F: 92	Injury history	0.41
		Injury history: Males	1.09
		Injury history: Females	-0.36

[1]: Adjusted for other factors as appropriate (gender, years swimming, any injury history, and injury history to same anatomical location).

Appendix 5. Summary of studies investigating the association of shoulder range of movement (RoM)/shoulder flexibility, and shoulder laxity with shoulder pain

Reference	Subject Characteristic	Factor	Equivalent Effect Size (Cohen's d)
Tate et al. (2012)	8-11yr (n=42)	Shoulder Passive RoM: Flexion (Positive vs. Negative Pain, Dissatisfaction and Disability)	-0.90
	12-14yr (n=43)		0.09
	15-19yr (n=84)		-0.31
	23-77yr (n=67)		0.25
	8-11yr (n=42)	Shoulder Passive RoM: Flexion: Elbow flexed: Triceps tightness (Positive vs. Negative PDD)	-0.65
	12-14yr (n=43)		0.13
	15-19yr (n=84)		0.18
	23-77yr (n=67)		0.28
	8-11yr (n=42)	Shoulder Passive RoM: Lats tightness (Positive vs. Negative PDD)	-0.86
	12-14yr (n=43)		0.41
	15-19yr (n=84)		-0.10
	23-77yr (n=67)		0.02
	8-11yr (n=42)	Shoulder Passive RoM: External Rotation (Positive vs. Negative PDD)	0.02
	12-14yr (n=43)		-0.19

	15-19yr (n=84)		0.24
	23-77yr (n=67)		0.35
	8-11yr (n=42)	Shoulder Passive RoM: Internal Rotation (Positive vs. Negative PDD)	-0.76
	12-14yr (n=43)		-0.03
	15-19yr (n=84)		-0.12
	23-77yr (n=67)		-0.22
	8-11yr (n=42)	Normalised pec minor length (cm): Rest (Positive vs. Negative PDD)	-0.54
	12-14yr (n=43)		-0.13
	15-19yr (n=84)		-0.85
	23-77yr (n=67)		0.10
	8-11yr (n=42)	Normalised pec minor length (cm): Stretch (Positive vs. Negative PDD)	0.00
	12-14yr (n=43)		-0.17
	15-19yr (n=84)		-0.65
	23-77yr (n=67)		0.05
Walker et al. (2012)	M: 37; F: 37	SSI: Low External Rotation RoM (<93˚ vs. middle tertile)	1.92
		SSI: High External Rotation RoM (>100˚ vs. middle tertile)	1.97
		SIP: Low External Rotation RoM (<93˚ vs. middle tertile)	1.39
		SIP: High External Rotation RoM (>100˚ vs. middle tertile)	1.15
Harrington et al. (2014)	F (37)	Dominant Arm: ER RoM (Positive vs. Negative Pain, Dissatisfaction and Disability)	0.31
		Dominant Arm: IR RoM (Positive vs. Negative PDD)	0.46
		Dominant Arm: Pectoralis Length: Rest (Positive vs. Negative PDD)	-1.14
		Dominant Arm: Pectoralis Length: Stretch (Positive vs. Negative PDD)	-0.81
		Non-dominant Arm: ER RoM (Positive vs. Negative PDD)	0.11
		Non-dominant Arm: IR RoM (Positive vs. Negative PDD)	-0.5
		Non-dominant Arm: Pectoralis Length: Rest (Positive vs. Negative PDD)	-0.29
		Non-dominant Arm: Pectoralis Length: Stretch (Positive vs. Negative PDD)	-0.03
Bak and Magnusson (1997)	M: 9; F: 6	ER RoM: Injured vs. Control	0.33
		ER RoM: Injured vs. Healthy	0
		IR RoM: Injured vs. Control	-1.03
		IR RoM: Injured vs. Healthy	-0.26
Beach et al. (1992)	M: 8; F: 24	Shoulder RoM: Left Flexion (correlation with shoulder pain)	0.61
		Shoulder RoM: Right Flexion (correlation with shoulder pain)	0.39
		Shoulder RoM: Left Extension (correlation with shoulder pain)	0.43
		Shoulder RoM: Right Extension (correlation with shoulder pain)	-0.02
		Shoulder RoM: Left Horizontal Abduction (correlation with shoulder pain)	0.24
		Shoulder RoM: Right Horizontal Abduction (correlation with shoulder pain)	-0.3
		Shoulder RoM: Left Horizontal Adduction (correlation with shoulder pain)	0.24
		Shoulder RoM: Right Horizontal Adduction (correlation with shoulder pain)	-0.61
		Shoulder RoM: Left External Rotation (correlation with shoulder pain)	0.16
		Shoulder RoM: Right External Rotation (correlation with shoulder pain)	0.54
		Shoulder RoM: Left Internal Rotation (correlation with shoulder pain)	0.02
		Shoulder RoM: Right Internal Rotation (correlation with shoulder pain)	-0.06
		Shoulder RoM: Left Abduction (correlation with shoulder pain)	-0.06
		Shoulder RoM: Right Abduction (correlation with shoulder pain)	-0.56
McMaster et al. 1998	M: 27: F: 13	Laxity Clinical Examination Score: Pain vs. no pain	0.98
Borsa et al. (2005)	M: 26; F: 16	Mean Anterior Glenohumeral Joint Displacement (swimmers vs. non-swimmers)	0.05
		Mean Posterior Glenohumeral Joint Displacement (swimmers vs. non-swimmers)	0.16

		Mean Anterior Glenohumeral Joint Displacement (pain vs. no-pain)	0.1
		Mean Posterior Glenohumeral Joint Displacement (pain vs. no-pain)	0.12
Bansal et al. (2007)	M: 161	Mean Shoulder RoM: Right External Rotation (with vs. without SIS)	0.17
		Mean Shoulder RoM: Left External Rotation (with vs. without SIS)	0.19
		Mean Shoulder RoM: Right Internal Rotation (with vs. without SIS)	0.07
		Mean Shoulder RoM: Left Internal Rotation (with vs. without SIS)	0.09

PDD: Shoulder Pain, Dissatisfaction and Disability); SSI: Significant Shoulder Injury; SIP: Significant Interfering Shoulder Pain; IR: Internal Shoulder Rotation; ER: External Shoulder Rotation.

Appendix 6. Summary of studies investigating the association of shoulder strength and shoulder problems

Reference	Subject Notes	Factor	Equivalent Effect Size (Cohen's d)
Tate et al. (2012)	8-11yr (n=42)	Strength (Nm/kg): Shoulder Elevation (Shoulder PDD vs. No PDD)	0
	12-14yr (n=43)		0.55
	15-19yr (n=84)		0.55
	23-77yr (n=67)		0.00
	8-11yr (n=42)	Strength (Nm/kg): External Shoulder Rotation (Shoulder PDD vs. No PDD)	0.00
	12-14yr (n=43)		0.00
	15-19yr (n=84)		0.00
	23-77yr (n=67)		0.00
	8-11yr (n=42)	Strength (Nm/kg): Internal Shoulder Rotation (Shoulder PDD vs. No PDD)	0.00
	12-14yr (n=43)		-1.02
	15-19yr (n=84)		0.00
	23-77yr (n=67)		0.00
	8-11yr (n=42)	Strength (Nm/kg): Horizontal Abduction (PDD vs. No PDD)	1.02
	12-14yr (n=43)		0.00
	15-19yr (n=84)		0.00
	23-77yr (n=67)		0.00
Harrington et al. (2014)	F (37)	Dominant Arm: IR Strength (%BW) (PDD vs. No PDD)	0
		Dominant Arm: ER Strength (%BW) (PDD vs. No PDD)	0
		Dominant Arm: Scapular depression Strength (%BW) (PDD vs. No PDD)	-0.26
		Dominant Arm: Scapular Adduction (%BW) (PDD vs. No PDD)	-0.31
		Non-dominant Arm: IR Strength (%BW) (Positive vs. Negative PDD) (PDD vs. No PDD)	0.26
		Non-dominant Arm: ER Strength (%BW) (Positive vs. Negative PDD) (PDD vs. No PDD)	0.51
		Non-dominant Arm: Scapular depression Strength (%BW) (Positive vs. Negative PDD) (PDD vs. No PDD)	-0.44
		Non-domant Arm: Scapular Adduction (%BW) (Positive vs. Negative PDD) (PDD vs. No PDD)	-0.51
Bak and Magnusson (1997)	M (9); F (6)	Concentric External Rotation Strength: Injured side vs. Control Group (Nm/kg)	0.27
		Concentric External Rotation Strength: Injured side vs. Healthy side (Nm/kg)	-0.11
		Concentric Internal Rotation Strength: Injured side vs. Control Group (Nm/kg)	-1.5
		Concentric Internal Rotation Strength: Injured side vs. Healthy side (Nm/kg)	-0.59
		Eccentric External Rotation Strength: Injured side vs. Control Group (Nm/kg)	0.14
		Eccentric External Rotation Strength: Injured side vs. Healthy side (Nm/kg)	0.45
		Eccentric Internal Rotation Strength: Injured side vs. Control Group (Nm/kg)	-1.1
		Eccentric Internal Rotation Strength: Injured side vs. Healthy side (Nm/kg)	-0.49
		Concentric ER: Concentric IR (Conventional): Injured side vs. Control Group	1.66
		Concentric ER: Concentric IR (Conventional): Injured side vs. Healthy side	0.36
		Eccentric ER: Eccentric IR (Conventional): Injured side vs. Control Group	0.45
		Eccentric ER: Eccentric IR	-0.56

		(Conventional): Injured side vs. Healthy side	
		Eccentric ER: Concentric IR (Functional): Injured side vs. Control Group	1.7
		Eccentric ER: Concentric IR (Functional): Injured side vs. Healthy side	1.24
		Shoulder Abduction: Injured side vs. Healthy side	-0.11
		Shoulder Abduction: Injured side vs. Control Group	0.23
		Supraspinatus muscle function: Injured side vs. Healthy side	-0.49
		Supraspinatus muscle function: Injured side vs. Control Group	-0.2
		Shoulder flexion: Injured side vs. Healthy side	-0.2
		Shoulder flexion: Injured side vs. Control Group	0
Beach et al. (1992)	M (8); F (24)	ER/IR Strength Ratio: Left (Correlation with Shoulder Pain)	-0.06
		ER/IR Strength Ratio: Right (Correlation with Shoulder Pain)	-0.24
		Abduction/Adduction Strength Ratio: Left (Correlation with Shoulder Pain)	0.28
		Abduction/Adduction Strength Ratio: Right (Correlation with Shoulder Pain)	-0.12
		Endurance Ratio: ER: Left	-1.54
		Endurance Ratio: ER: Right	-1.91
		Endurance Ratio: IR: Left	-0.49
		Endurance Ratio: IR: Right	-1.04
		Endurance Ratio: Abduction: Left	-1.32
		Endurance Ratio: Abduction: Right	-1.62
		Endurance Ratio: Adduction: Left	-0.02
		Endurance Ratio: Adduction: Right	0.14

PDD: Shoulder Pain, Dissatisfaction and Disability); IR: Internal Shoulder Rotation; ER: External Shoulder Rotation.

Appendix 7. Summary of studies investigating the association of general strength and shoulder problems

Reference	Subject Notes	Factor	Equivalent Effect Size (Cohen's d)
Tate et al. (2012)	8-11yr (n=42)	Core Endurance: Side Bridge (Shoulder PDD vs. No PDD)	-0.1
	12-14yr (n=43)		-0.57
	15-19yr (n=84)		-0.4
	23-77yr (n=67)		-0.53
	8-11yr (n=42)	Core Endurance: Prone Bridge (Shoulder PDD vs. No PDD)	-0.13
	12-14yr (n=43)		-0.47
	15-19yr (n=84)		-0.46
	23-77yr (n=67)		0.13
	8-11yr (n=42)	Core Endurance: Closed kinetic chain stability test (Shoulder PDD vs. No PDD)	0.37
	12-14yr (n=43)		-0.52
	15-19yr (n=84)		0.18
	23-77yr (n=67)		0.19
Harrington et al. (2014)	F (37)	Dominant Arm: Prone Bridge (PDD vs. no PDD)	-0.16
		Dominant Arm: Side Bridge (PDD vs. no PDD)	-0.16
		Non-dominant Arm: Prone Bridge (PDD vs. no PDD)	0.14
		Non-dominant Arm: Side Bridge (PDD vs. no PDD)	-0.19

PDD: Shoulder Pain, Dissatisfaction and Disability.