Shoulder injury in water polo: a systematic review of incidence and intrinsic risk factors.

Abstract

Background: Water polo is a popular water-based contact sport that involves swimming, throwing and defending. Cumulatively, these repetitive overhead activities are thought to increase the risk of shoulder injury and, subsequently to affect players’ physical conditioning as well as team performance.

Objective: To examine available evidence relating to shoulder injury rates and risk factors for shoulder injury in water polo.

Methods: CINAHL, AUSPORT, Pubmed, Pedro and SPORTDiscus databases were searched for original research papers using the predefined terms ("water polo") AND (shoulder OR glenohumeral* OR arm OR "upper limb").

Results: Twenty papers were identified as suitable for inclusion. Reported shoulder injury rates varied from 24%-51%. Shoulder injuries were more likely to become chronic compared to all other reported injuries. Injury data during the last three World Championships indicates an increasing rate of shoulder injuries-per-year with participation in aquatic sports. Risk for shoulder injury in water polo is multi-factorial. Volume of shooting, range of motion, scapular dyskinesis, strength imbalance, proprioceptive deficit and altered throwing kinematics have been proposed to be associated with an increased risk of injury

Conclusion: Although this review showed water polo to have a high propensity for shoulder injury, the descriptive nature of the included papers limited the inferences that could be drawn from the pooled literature. Future directions for research include collecting normative data for shoulder range of motion, strength ratio and proprioception with prospective analysis of these attributes in relation to injury rates and time lost.

Keywords: Athletes; muscle strength; range of motion; proprioception; upper limb
i. Introduction

Water polo originated in the mid-19th century in England and Scotland as an aquatic form of rugby.¹ Men’s water polo was introduced at the modern Olympics in 1900 making the sport of water polo the first Olympic team competition.² Presently, the International Swimming Federation (FINA) is the international governing body for the sport.³

Water polo is a physically demanding sport, particularly on athletes’ upper limbs, with intense bursts of sprint swimming, changing direction every 6.2s⁴, and passing and shooting the ball repetitively from end-of-range shoulder abduction (Abd) and external rotation (ER) at arm speeds of up to 24.1±1.58 ms⁻¹.⁵

Risk factors identified for shoulder pain in swimmers are often extrapolated to water polo, despite the unique demands. Unlike competitive swimmers, water polo players use an adapted upright swimming posture to allow transport of the ball and a clear view of the opposition. The elevated posture eliminates the body roll observed in traditional freestyle swimming, increasing the required shoulder Abd and internal rotation (IR) and placing stress on the rotator cuff.⁶ Also in contrast to swimming, water polo is a contact sport. In defensive play, athletes keep their arms above their head to physically obstruct the opposition and block opposing players’ throws, placing external force on the shoulder joint.⁷,⁸

The aquatic environment means that water polo players generate throwing force without the contribution of a solid base of support, making it difficult to produce the conventional throwing proximal-distal kinematic chain sequence.⁶,⁹ When throwing in water polo, power is produced by the trunk rotating forward from hyperextension to 20° flexion to maximise shoulder ER by leaving the arm and ball behind the body (Figure 1).⁹ The arm then moves in an arc, shifting the body towards the horizontal plane as the trunk simultaneously laterally flexes away from the throwing arm, increasing the height and velocity for ball release.⁹,¹⁰
Despite the lower average ball velocity observed in water polo (16.5ms$^{-1}$) compared to baseball (33ms$^{-1}$) and American football (23ms$^{-1}$), resultant joint torques is similar.\textsuperscript{11} Horizontal adduction and IR torque in the penalty shot is 64/59Nm compared to 100/67Nm and 78/66Nm for baseball and American football respectively.\textsuperscript{10, 12, 13} The observed force can be explained by the larger size and weight of the water polo ball (400-450g) compared to baseball, and the reduced contribution of the lower extremity to the kinetic chain.\textsuperscript{10, 14, 15}

The aim of this paper was to review the available literature regarding shoulder injury rates and risk factors for shoulder injury in water polo. It has been previously suggested that shoulder injury rates are as high as 80\% in elite water polo,\textsuperscript{1, 6, 16} however due to limited research results are often extrapolated from other overhead sports. Evaluation of the incidence of shoulder injury and the relationship between intrinsic risk factors and shoulder injury may help identify “at risk” athletes and enable targeted injury prevention strategies. Further, this review serves to identify current gaps in water polo research regarding shoulder injury rates, normative data and risk factors associated with shoulder injury.
ii. Methods

CINAHL, AUSPORT, Pubmed, Pedro and SPORTDiscus databases were searched using the key terms ("water polo") AND (shoulder OR glenohumeral* OR arm OR "upper limb"). No date limits were applied and the search was completed in August 2016. Two reviewers conducted the selection process and independently evaluated the characteristics and key outcomes of the study. Studies were included if they were in English and original research, and could be anthropometrical, descriptive, epidemiological or interventional. No restriction was placed on player’s age or competition level. Studies were excluded if multiple overhead sports were aggregated in the analysis or if non-conservative/surgical interventions were applied. The sequence of paper selection is presented in Figure 2.

Articles were divided by the main themes of injury incidence, pain, strength, ROM, proprioception, pathoanatomy and posture. The quality of the final study yield was analysed using a modified version of the Critical Review Form for Quantitative Studies. To enable a numerical result each criterion was evaluated using a dichotomous ‘yes’ =1, no or not applicable =0 for a total achievable score of 12, with a score of greater than 50% required for inclusion. Final study ratings were collated and inter-rater difference discussed in a consensus meeting. The quality score and outcome summary is reported in Table 1.
Figure 2 PRISMA flow diagram. $n =$ number

Records identified through database searching
(n = 122)

Additional records identified from hand searched reference lists
(n = 7)

Records after duplicates removed
(n = 84)

Records screened
(n = 84)

Records excluded
(n = 45)

Full-text articles assessed for eligibility
(n = 39)

Full-text articles excluded, with reasons
(n = 19)
- No statistics – 8
- Abstract only – 2
- Case report – 2
- Surgical intervention – 2
- Mixed sports – 3
- Elbow – 1
- Not original research - 1

Studies included in review article
(n = 20)
### iii. Results

The review process returned 20 papers. Six papers considered epidemiology of shoulder pain and injury and the remaining 14 investigated intrinsic risk factors of shoulder injury in water polo players. Injury incidence was defined as the number of new injuries in a specified time period,\(^\text{18}\) and injury rate as the number of injuries divided by athlete-time-exposure.\(^\text{19}\)

**Shoulder injury incidence at major championships.** Three studies evaluated shoulder injury incidence at major international championships.\(^\text{7, 8, 20}\) A cohort study of male water polo players competing at the 2004 Summer Olympics reported that 53% of injuries affected the head/neck, 12% the trunk and 6% the shoulder.\(^\text{7}\) Retrospective analysis of the 2009 FINA World Championships revealed that upper-limb injury was highest in water polo compared to other aquatic sports, with 37% of the total injuries (n=48) being reported by water polo athletes, of which 19% affected the head/neck region and 12.5% affected the shoulder.\(^\text{20}\) Analysis of injury incidence prior to and during the 2013 FINA World Championships demonstrated that water polo had the highest injury rate compared to all other aquatic sports (15.3 injuries/100-athletes) followed by open water swimming (11.7) and diving (11.4).\(^\text{8}\) Of injuries to the head and neck across all sports, water polo was responsible for two-thirds of the total number of injuries (n=23). The most frequently-injured body part at the World Championships was the shoulder (n=39, 21%) and 25% of injuries that resulted in time loss were shoulder injuries (n=28); although the percentages for each sport were not reported. A more recent review of the last three FINA World Championships, confirms the shoulder was the most commonly affected anatomical site for aquatic athletes.\(^\text{21}\)

**Shoulder injury incidence.** The other three epidemiological studies obtained documented anatomical site and injury incidence in water polo players and all found shoulder injury the most prevalent.\(^\text{22-24}\) Ellapen et al.\(^\text{24}\) prospectively examined the prevalence of musculoskeletal pain in adolescent male water polo players. During the 12-month study period, the shoulder accounted for over half (51%) of all injuries sustained. A 13-year retrospective study was conducted on male water polo scholarship holders at the Australian Institute of Sport (AIS). Of all anatomical sites, the shoulder had the highest reported clinical incidence (n=67), comprising 24% of total injury over the 13-year period, and
shoulder injuries were also more likely to become chronic. Sallis et al. was the only author to consider gender differences and injury incidence, with injuries at a single NCAA-Division-III college compared over a 15-year period. A statistically significant gender difference (p<0.01) was found for shoulder injury, with female water polo players reporting 2.38 times the rate (3.40 vs 8.09/100 participant years) of shoulder injury compared with men.

**Shoulder pain and patho-anatomy.** Three studies considered shoulder pain. Wheeler et al. found 74% of shoulder soreness could be explained by the total volume of shooting and reduced rest between shots. All athletes reported moderate soreness (2.9±1.3) on an increasing 10-point likert scale, and shoulder soreness was associated with performing a greater number of shots. Shoulder soreness was shown to increase with an average rest time of <508s between shots in the squad selection camp and <160s in the team game-based camp. Giombini et al. compared magnetic resonance imaging (MRI), clinical tests and arthroscopic investigation in 11 water polo players with shoulder pain and demonstrated posterior-superior glenoid rim impingement to be a contributing cause of pain in elite-level water polo players. All the players demonstrated internal impingement, thought to be from repetitive positioning of the shoulder in maximum ER/Abd in the cocking phase of throwing. Klein et al. conducted a cross-sectional study, comparing 28 semi-professional water polo players to healthy age-matched controls, but found no significant correlation between clinical presentation and imaging results. When viewed on MRI, water polo players had significantly more changes in subscapularis (p=0.001) and infraspinatus tendons (p=0.024) and the posterior labrum (p=0.041) than age-matched controls. All 28 players’ throwing shoulders demonstrated abnormal findings on MRI, despite only 29% being symptomatic.

**Posture and shoulder injury.** Water polo athletes with reduced pectoralis-minor length demonstrated altered scapular kinematics; that is, less posterior scapular tilting and greater IR with humeral elevation. Scapular muscle imbalance from reduced pectoralis-minor length may lead to dyskinesis, increasing glenohumeral contact and impingement of the rotator cuff. In players with shoulder pain, upward scapular rotation has been shown to decrease after intense practice, potentially increasing the risk of impingement of the rotator cuff. Two studies considered the role of posture.
profile and injury rates and both demonstrated a positive relationship between a kyphotic posture and shoulder pain in water polo.24, 30 25% of included players reported a previous shoulder injury (elbow-11%, back-6%) and 8% reported recent shoulder injury; 67% of players with recent shoulder injury had a protracted shoulder posture.30

Shoulder ROM. In college water polo players’ significantly greater ER ROM (83.8±10.9° v 77.5±18.2° p<0.001) and total ROM (132.1±17.4° v 127.4±18.2° p=0.04) has been reported for the throwing vs non-dominant arm.31 Witwer and Sauers31 attribute this adaptation to elongation of the inferior glenohumeral ligament arising from the repetitive ER and preservation of IR with swimming demands. In contrast, results from Elliot32 demonstrated elite water polo players to have significantly greater bilateral shoulder flexion ROM (p<0.01) compared to controls, and reduced unilateral IR of their throwing arm (p<0.01). No significant correlation was found between shoulder range and pain.

Shoulder strength. Although water polo players are stronger than age and gender-matched controls, rotator cuff muscle imbalance may be present due to greater IR than ER development occurring in water polo players.33-36 Of the four studies reviewed, only one reported the expected ratio for a throwing population for IR:ER of 1.0:0.6736 with the other three varying between 1.0:0.50 –1.0:0.6033-35 indicating an increased IR strength and/or relative decrease in ER strength.

Throwing and shoulder injury. While shooting a penalty goal, kinematic differences at the elbow were observed in players with shoulder pain, with injured athletes demonstrating lower peak angular velocity and less elbow flexion early in the throw cycle.37 A more recent investigation suggests that male water polo players’ throwing velocity has improved over time from 19.7±0.4ms⁻¹ to 24.1±1.58ms⁻¹.5 However, despite this improvement in throwing velocity, no change in kinematic variables was observed between athletes with and without shoulder pain. Further investigation of this performance phenomenon including specific weight training and talent selection is recommended.5

Proprioception and strength. Mota and Ribeiro,36 evaluated the relationship between shoulder proprioception and strength of the shoulder rotators. Greater sensory acuity through improved proprioception is suggested to contribute to enhanced motor control of the joint.38
proprioception, and its association with strength, may improve training and injury prevention strategies. Proprioception acuity at 30°ER was negatively correlated with both eccentric-ER and concentric-IR peak torque in this position. These main findings suggest that the tested cohort of athletes may be more prone to injury. Reduced proprioception acuity may lead to a delayed neuromuscular protective reflex and the resultant shoulder rotator muscle contraction may be insufficient to protect the joint from excessive movement.
iv. Discussion

Previous descriptive reports have suggested shoulder injury rates in elite water polo are as high as 80%,\textsuperscript{1, 6, 16} In contrast, the present review found injury rates for elite male water polo players was 24% and up to 51% for college level males.\textsuperscript{22, 24} Due to methodological limitations of retrospective studies, such as incomplete medical records and failure to report injury re-occurrence, future prospective studies with a clear definition of ‘injury’ as well as capturing time-loss to sport participation and recording injury recurrence are necessary.

A trend toward increasing rates of shoulder injury during major international championships was observed, with shoulder injury rates doubling between the 2004 Summer Olympics and 2009 FINA World Championships from 6% to 13%.\textsuperscript{7, 20} A contributing factor may have been the rule change in 2005, whereby the maximum period for keeping the ball was reduced from 35s to 30s.\textsuperscript{39} While this change increased the speed and the appeal of the game, the rise in throwing frequency may explain the increased number of shoulder injuries. Interpretation of the incidence of injury during the 2009 championships is limited somewhat by the low response rates from team physicians (53%).\textsuperscript{20} Given the high rates of shoulder injury in water polo, risk of chronicity and potential ensuing detraining effects on overall performance, research focussing on reducing shoulder injury frequency in this population is warranted. A need exists for implementation of injury prevention strategies at an organisational level targeting the shoulder, such as introducing daily monitoring of athletes’ pain and conducting regular evidence-based musculoskeletal screening to enable targeted and early intervention for at-risk athletes.\textsuperscript{40}

It remains unclear whether shoulder injury risk is gender or sport-specific. Only one study investigated gender differences in water polo injury rates\textsuperscript{23} with nearly 2000 injuries recorded during a 15-year period. All injuries were evaluated using a standardised injury form completed by the same athletic trainer. Female water polo players were nearly three times more likely to sustain a shoulder injury than their male counterparts. Although a statistically significant difference was found between genders, no injury severity or time-loss data was recorded, limiting the clinical significance of the findings. Authors suggested the increased injury rate may be attributed to a more rigorous training program for
the female players. Gender related differences have been previously demonstrated in anterior cruciate ligament injury rates, and one may question whether greater shoulder laxity and less relative strength may be similarly contributing to increased shoulder injury in female water polo players. With increasing participation of women in water polo, further investigation is required to determine if shoulder injury is related to the demands of the sport or if gender-specific risk factors exist that could be addressed.

The repetitive stress placed on the athlete's shoulder joint complex during the throwing motion challenges the physiological limits of the surrounding tissues. Increased shot frequency was associated with shoulder soreness, and thresholds were specific to individual athletes, with 29% of soreness prediction based on individual differences. These findings highlight the importance of coaches developing individual athlete thresholds to enhance performance and reduce injury risk through optimising training load and substitution of athletes during a game.

In terms of the mechanics of the water polo throwing action, two contradictory views exist regarding humeral translation occurring during the cocking phase. One view suggests that the humeral head translates postero-superiorly and is associated with thickening of the posterior capsule and development of internal impingement while the other suggests that repeated Abd and ER is associated with anterior-inferior translation and resultant anterior instability and attenuation of the capsule. Giombini et al. concluded that a primary cause of pain in water polo players was posterior-superior glenoid impingement however no asymptomatic water polo players or healthy controls were included for comparison. In contrast, Klein et al. when comparing water polo players to healthy age-matched controls, found no correlation between clinical presentation and imaging results. Both authors agree the action of overhead throwing causes anatomical changes to the posterior labrum. The notion of the labrum as a primary pain source, however, requires further investigation before a link between shoulder pain, throwing and labral pathology in water polo can be confirmed. Anatomical changes of the labrum on MRI may not indicate pathology and should not be used as the basis for intervention in a throwing population. Rather it is recommended that team physiotherapists consider an athlete’s
clinical history, clinical examination findings, functional limitations and radiological results together when developing a management strategy.14, 45, 46

One proposed mechanism for altered scapular kinematics is change in pectoralis-minor length.47 Water polo athletes with reduced pectoralis-minor length demonstrate altered scapular kinematics which may lead to dyskinesia, increasing glenohumeral contact and risk of rotator cuff impingement.27, 29 It has previously been demonstrated that a forward scapular position can result from posterior shoulder tightness and alteration in shoulder and scapular muscle activity pattern.46 Clinically, the presence of scapular asymmetry in a throwing athlete is nearly universal, however pain is not.46 Given that visual assessment of scapular dyskinesis has demonstrated validity for athletes engaged in overhead sport26, 48 inclusion of the assessment of scapular dyskinesis in water polo athletes’ musculoskeletal screening has merit and may enable targeted stretching for athletes at increased risk of developing shoulder pain. However, testing needs to consider the larger clinical picture including posterior shoulder muscle length, muscle strength and activity pattern.

College level water polo players demonstrated greater ER ROM in their dominant compared to non-dominant shoulder, attributed to acquired changes from repetitive overhead activity.31 As goniometry was used to measure ROM instead of ultrasound it is not possible to determine whether osseous or soft tissue adaptations account for the observed changes in ROM. Previous research in baseball indicates that throwing between the ages of 11-16 years is critical in the development of humeral retroversion49, but the required loads for the development of torsional change is unknown.46 Given the later age that water polo players commence training, it is proposed that the osseous adaptation of the humerus observed in baseball would not have as many years to develop.31 Further, the stresses placed on the shoulder joint in water polo are different and require a combination of swimming and to a lesser extent overhead throwing. The difficulty lies in differentiating between advantageous adaptive and pathological change in ROM. Internal impingement is thought to be a normal phenomenon and the true pathological process is when loss of IR exceeds gains in ER.42 Baseball players (unilateral) and swimmers (bilateral) demonstrate a relative increase in ER and a corresponding loss in IR.50, 51 In elite level water polo players, Elliot32 found a similar imbalance in shoulder flexibility; a bilateral increase
in ER and unilateral decrease in IR (throwing arm). In contrast, college level water polo players’
throwing arm IR ROM was preserved, and an increase in ER without a loss of IR is observed.\textsuperscript{31} It is
unclear at what point these observed changes in ROM are a predisposing factor to shoulder injury in
water polo, as only pain-free college level athletes were included\textsuperscript{31} and no significant correlation was
found between ROM and pain in the elite population.\textsuperscript{32} Accordingly, investigation of water polo
players with and without shoulder pain to establish normative ranges and injury risk is required.

The overhead throw is the most effective method for accelerating the ball and is critical to success and
scoring goals in water polo. Although elements of shooting efficiency are a trained skill, the
assumption is that the faster the ball travels, the harder it is for the goalie to deflect the shot.\textsuperscript{52} Water
polo players demonstrated increased strength in IR and ER compared to gender matched controls,
however a rotator cuff muscle imbalance exists due to greater relative IR than ER strength.\textsuperscript{33-36} It has
been proposed that the risk of shoulder injury is therefore increased due to insufficient ER strength to
balance and decelerate the shoulder in the follow through phase of throwing.\textsuperscript{33-35} Isokinetic shoulder
strength was measured as it is considered an important parameter to predict throwing performance,
however no change in throwing velocity was observed following a shoulder strengthening program
despite significant increase in strength.\textsuperscript{35} Participants may have traded off velocity for accuracy though
due to a target being used to measure throwing performance. Further investigation is required to
clarify the relationship between throwing speed and shoulder strength. A systematic review of
shoulder rotation strength in baseball players recommends IR:ER of greater than 1.0:0.67.\textsuperscript{46} Normative
pre-season strength data of baseball players has shown a correlation between increased IR and reduced
relative ER strength as a predictor of in-season shoulder injury risk.\textsuperscript{53} This data provides an evidence-
based foundation for the assessment of water polo players, however due to the known difference in
throwing mechanics, a need exists for standardised normative data within water polo in order to guide
strength and conditioning and rehabilitation protocols.

Kinematic differences at the elbow while shooting a penalty goal have been demonstrated in elite
players with and without shoulder pain, however, it is unclear whether this different kinematic profile
contributes to development of shoulder injury due to some individuals within the injured and non-
injured group performing similarly. The study groups were also not homogenous at baseline as non-
injured athletes had lower mean body weight and height. One of the major limitations of kinematic
investigations of the shoulder in water polo is demonstrating the contribution of the superficial and
deep shoulder cuff muscles to movement and stability. Superior throwing performance has been
shown to be characterised by decreased movement variability at critical points within the penalty
shot. Although shooting proficiency is adversely affected by increased exertion, height out of the
water, elbow angle and position at release, ball speed and accuracy were all maintained under
fatigue. Reduction in movement variability at the elbow before ball release suggests that a threshold
may exist to improve throwing accuracy and potentially reduce injury risk. The role of technique in
injury-risk and conversely injury causing change in throwing technique is unclear and requires further
investigation. Water polo is an intermittent and high intensity sport and incremental fatigue causes
decrement in throwing performance. To improve athletes throwing proficiency, the literature
demonstrates value in coaches focussing on increasing athletes overall fitness as well as practicing
throwing skill under pre-fatigue conditions.

Dynamic shoulder stability is derived from muscular as well as neuromuscular control. Recent
research has shown that the quality of an individual’s proprioception is associated with the level at
which they perform in their sport. It may therefore be expected water polo athletes would
demonstrate superior proprioception; however in sports involving overhead activities, the shoulder can
show proprioceptive deficits. Joint proprioception has been shown to be impaired further into
range in people with chronic shoulder injuries. The increased ROM developed from repeated
throwing may, over time, induce trauma to the shoulder capsule damaging mechanoreceptors,
reducing afferent input and increasing the risk of shoulder injury. In baseball, repetitive throwing
has been shown to reduce proprioception acuity but not an athlete’s shoulder strength. Despite
reduced proprioception, power remained unaffected, suggesting an increased injury risk from the
impact of fatigue on proprioception, before a reduction in performance was observed. There is limited
research of mechanisms to enhance proprioception; however, it is known that improved proprioception
is trainable in the lower leg and the knee region. Preliminary work suggests reduced proprioception
in water polo players may increase the risk of injury.\textsuperscript{36} To date, no study has measured proprioception of water polo athletes in their aquatic playing environment. Accordingly, potential exists for proprioceptive training of the shoulder region to be applied within a water polo context but further research is required with high ecological validity, a larger sample size and inclusive of both male and female athletes for a more robust analysis of the correlation of proprioception and injury risk.

This systematic review was limited by the heterogeneity of the included studies preventing quantitative statistical analysis. Results reporting was biased by lack of consensus regarding the definition of injury, as some studies did not include a working definition of injury\textsuperscript{30, 32, 37}, injury severity\textsuperscript{7, 23, 30} or athlete exposure/risk.\textsuperscript{7, 24, 30} Included studies were of a small study size,\textsuperscript{15, 25, 31, 36} and are limited by the risk of recall bias due to self-report questionnaires,\textsuperscript{8, 24} no control group in intervention studies,\textsuperscript{25, 31, 32} and non-homogenous groups at baseline.\textsuperscript{14, 37} Differences in methodological quality of the included studies were compared, however readers are cautioned when interpreting results as some selected outcome measures may not have been sensitive to detect change (measurement bias).\textsuperscript{5, 33, 35} Results are further limited by selection bias and may not be generalisable to the wider water polo population due to inclusion of elite athletes only.\textsuperscript{5, 7, 8, 14, 15, 20, 22, 25, 32-34, 37}
v. Conclusion

Review of the current literature indicates that shoulder pain and injury are common in water polo with reported rates for male players ranging from 24% – 51%. Risk for shoulder injury is multifactorial, however the relative contribution of intrinsic factors remains unclear.

Future implications for research include development of normative data sets in water polo regarding shoulder ROM, strength ratio and proprioception. Simultaneously, further prospective analysis with a clear definition of injury incidence and rate and that details time loss/injury severity is required. Results would enable more targeted and comprehensive injury prevention interventions to be developed by physiotherapists, coaches and strength and conditioning trainers.

Practical implications for training include monitoring individual athletes’ shot frequency and rest intervals in conjunction with daily shoulder pain reporting to allow individualised athlete loading. Regular musculoskeletal screening of water polo players for risk factors for shoulder injury is advised and should include; visual assessment of athlete’s posture and rating of scapular dyskinesis to enable targeted muscle stretching prescription. Similarly, measurement and preservation of IR ROM needs to be monitored and assessment and maintenance of shoulder ER strength relative to IR, to ensure a minimum ratio of IR:ER of 1.0:0.67 is achieved. Alongside posture, ROM, strength, daily pain and training load monitoring, neuromuscular assessment and post-injury retraining are recommended.
vi. Practical implications

- For injury prevention, monitoring individual athlete loading and daily reported shoulder pain is encouraged.
- Visual assessment for scapular dyskinesis pre and post training can enable targeted shoulder stretching prescription.
- Measurement and preservation of dominant/throwing arm IR ROM is recommended.
- A shoulder strength ratio for IR:ER > 1.0:0.67 is desirable.
- For performance outcome, increased overall athlete fitness may improve athlete’s goal shooting accuracy.
vii. Acknowledgments

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duration of her PhD candidature
viii. References


ix. Table 1 Included studies. The key variables investigated and quality evaluation summary.

<table>
<thead>
<tr>
<th>Author/s Study design</th>
<th>Key variable</th>
<th>Participants</th>
<th>Level of WP</th>
<th>Results</th>
<th>Limitations</th>
<th>Quality Score</th>
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<tr>
<td>Shoulder Injury Incidence at major championships</td>
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<tr>
<td>Mountjoy et al. 8 Retrospective and prospective survey</td>
<td>Injury incidence at the 2013 FINA World Championship</td>
<td>Competed at FINA 2013 Age 24.5±4.23y. n=329 (Males 153, Females 176)</td>
<td>Elite</td>
<td>The most frequent injury, shoulder tendonosis (n=17). Primary MOI, contact with opposing player (n=46; 24.7%). Time loss: 8% of reported injuries resulted in of 1–2 weeks time loss, and 25% of all time-loss injuries were to the shoulder (n=28).</td>
<td>Data on time loss is missing in 53 (28%) cases.</td>
<td>9/12</td>
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<tr>
<td>Mountjoy et al. 20 Prospective survey</td>
<td>Injury incidence at the 2009 FINA World Championship</td>
<td>Competed at FINA 2009 Age – NS. n=461 (Males 235, Females 226)</td>
<td>Elite</td>
<td>Injuries per 1000 athletes; 89.4 men, 101.8 women. Competition injuries per 1000 starts; men 14.9, women 23.8. WP had the highest injury rate of the championship. 37% of the total injuries (n=48) reported WP athletes, of which 19% affected the head/neck region and 12.5% affected the shoulder.</td>
<td>Response rate 53.4%.</td>
<td>10/12</td>
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<tr>
<td>Junge et al. 7 Cohort study</td>
<td>Injury incidence during the 2004 Olympic Games</td>
<td>14 teams at 2004 Olympics Age – NS</td>
<td>Elite</td>
<td>The total incidence was 21 injuries per 1000 player matches (95% CI, 11-31). The majority of injuries affected the head (56%), followed by the upper extremity (28%), all injuries were incurred because of contact with another player. Men’s WP shoulder injury 6% of total injury.</td>
<td>No recording of time loss. Mean number of injuries per match disregards the number of players in a match and the duration.</td>
<td>8/12</td>
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<td>Shoulder Injury Incidence</td>
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<td>Annett, Fricker, McDonald 22</td>
<td>Male AIS athletes injury rate by 77 Male AIS WP Scholarship holders 1985 –</td>
<td>Elite</td>
<td>1.51 injuries/athlete/year. Shoulder injury most frequent 24.1%.</td>
<td>No recording of time loss. Retrospective design - reliance on completeness of</td>
<td>8/12</td>
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<td>Study Type</td>
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<tr>
<td>Retrospective cohort study</td>
<td>anatomical location and per playing hours 1998 Age 20y (16y 4m – 33y 6m) n=77 males</td>
<td>Overuse injury 50% shoulder (n=38). Chronic shoulder injury n=22, 38.6% of all chronic injuries.</td>
<td>Medical records. No indication of recurrence of injury.</td>
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<td>Ellapen et al.24</td>
<td>Injury rates and anatomical location in youth WP players Adolescent WP player residing in Kwa-zulu natal Age 16.34y n=100 males</td>
<td>72/100 players reported pain within last 12months, 51.04% of total injury was related to the shoulder, 23.95% knee, 17.71% vertebral. MOI = overuse (88%, p&lt;0.001)</td>
<td>Self-reported questionnaire – potential for recall bias</td>
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<tr>
<td>Prospective cohort study</td>
<td>Injury rate of collegiate sports by anatomical area and gender NCAA Div III athletes b/w 1980-1995 Age range 18-22y. n= 3796 (total for all sports)</td>
<td>Shoulder injury rate Male WP = 3.40/100 participants-years, Female = 8.09/100 participants-years (p&lt;0.001)</td>
<td>Did not consider injury trend over time. No injury severity recorded. No recording of time lost.</td>
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<td>Sallis et al.23</td>
<td>Shoulder pain AIS volunteers Age 23y (18-29y). n=7 Females</td>
<td>74% of shoulder soreness was explained by shooting volume (p=0.013). Prediction for soreness stronger during squad selection than team game (p=0.002). Shoulder soreness increased with a rest time of ≤508s b/w shots at squad selection and ≤160s in team based camp.</td>
<td>Sample size – 7. Shot intensity not considered.</td>
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<td>Wheeler et al.15</td>
<td>Shoulder pain AIS volunteers Age 23y (18-29y). n=7 Females</td>
<td>74% of shoulder soreness was explained by shooting volume (p=0.013). Prediction for soreness stronger during squad selection than team game (p=0.002). Shoulder soreness increased with a rest time of ≤508s b/w shots at squad selection and ≤160s in team based camp.</td>
<td>Sample size – 7. Shot intensity not considered.</td>
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<td>Giombini et al.25</td>
<td>Persistent shoulder pain Age range 17-29y. n=11; males 7, females 4</td>
<td>MRI showing damage to joint structures - 100% posterior-superior labral damage, partial tears of under surface of rotator cuff.</td>
<td>No control used, small sample size.</td>
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<td>Author(s)</td>
<td>Type</td>
<td>Description</td>
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<td>Elliott</td>
<td>Descriptive study</td>
<td>Shoulder ROM of members of GBR WP team</td>
<td>No current shoulder pain</td>
<td>Age 25y (20-35y). n=25 males; WP 13, controls 12</td>
<td>WP players greater flexion bilaterally and reduced IR on dominant/preferred throwing arm. No relationship between ROM and pain. WP Flexion, Dominant = 182±15°, Non-dominant = 180±15° Control (158±11°, 159±10°, p&lt;0.001) WP IR, dominant = 45.4±12.2°, non-dominant 50.8±11.1° (p&lt;0.01) Control (54.6±16.4°, 55.0±14.4°)</td>
<td>No relationship b/w ROM and pain but excluded WP players who had pain limiting ROM.</td>
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<td>Witwer and Sauers</td>
<td>Repeated measures</td>
<td>Should Prom IR/ER</td>
<td>NCAA div I</td>
<td>Age 19.9±1.1y n=31; males 12, females 19</td>
<td>No significant difference was observed between L) and R) sides for scapular upward rotation, posterior shoulder tightness or IR. A significant difference between sides was observed for ER ROM for the dominant vs non-dominant shoulder (83.8±10.9°, 77.5±11.9° p &lt; 0.0001) and total ROM (132.1±17.4°, 127.4±18.4° p = 0.039).</td>
<td>Small population. Inluded athletes were pain free only so it is not possible to determine what role these clinical measures of shoulder mobility play in the development of shoulder pathology.</td>
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<td>Tsekouras et al.</td>
<td>Descriptive study</td>
<td>Shoulder strength; IR/ER at 90/90</td>
<td>Elite WP player</td>
<td>Age 25.5±5.0y n=19 males</td>
<td>Maximum torque, IR 68.5±10.8 Nm ER 37.1±5.7 Nm. Ratio IR:ER 1.9:1.0.</td>
<td>Athletes play in the same team. No indication of shoulder pain or history.</td>
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<td>McMaster, Long, Caiozzo</td>
<td>Descriptive study</td>
<td>Shoulder strength; Add/Abd, shoulder ER/IR</td>
<td>USA Men’s national team</td>
<td>Age= Control 22y, WP 26y n=25 males; WP 15, controls 10</td>
<td>Strength ratio’s Add:Abd 2.0:1.0, ER:IR 0.6:1.0</td>
<td>Only 10s rest between trials, insufficient recovery for maximal strength contraction.</td>
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<td>Bloomfield et al.\textsuperscript{35}</td>
<td>The effect of strength training on throwing velocity</td>
<td>Western AUS under 19 team</td>
<td>Elite</td>
<td>Throwing velocity positively correlated with standing height and body weight (p&lt;0.01). No change in overhead throwing velocity was observed post strength training intervention.</td>
<td>Outcome used measured accuracy and velocity and athletes may have trade of velocity for accuracy. Training stimulus too low for strength/power; 3 sets - 15 @ 50-60%, @70-80%, 8 @ 85-90%.</td>
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<td>Taylor, Landeo, Coogan.\textsuperscript{54}</td>
<td>Movement variability during WP shot</td>
<td>National AUS players</td>
<td>Sub-elite</td>
<td>Group mean elbow and wrist displacement at release were 133.7±8.2 and 122.7±20.6° respectively. Reduced variability at the elbow and wrist close to critical point of ball release.</td>
<td>Small sample size. Athletes were requested to start with arm elevated above water – not regular start position. Skill level of players sub-elite v elite.</td>
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<td>Melchiorri et al.\textsuperscript{5}</td>
<td>The effect of shoulder injury on throwing mechanics</td>
<td>Italian men’s national team</td>
<td>Elite</td>
<td>No statistically significant difference was observed between injured and non-injured players kinematics. No positive correlation b/w physical characteristics (weight/height) ball velocity. Average ball velocity 24.1±1.5ms\textsuperscript{-1}.</td>
<td>Goal keepers included in analysis, goals keepers had a significantly lower ball speed. Scapular kinematics and trunk rotation not included in analysis.</td>
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<td>Whiting et al.\textsuperscript{37}</td>
<td>Throwing velocity and kinematics with/without shoulder pain</td>
<td>US men’s national team</td>
<td>Elite</td>
<td>Lower peak angular velocity (injured, non-injured; 1104±72°/s, 1182±45°/s) and angular velocity (652±51°/s, 738±41°/s) at release in injured group. Ball velocity at release (19.9±0.7ms\textsuperscript{-1}, 19.3±0.5 ms\textsuperscript{-1}).</td>
<td>Group not homogenous at baseline, non-injured group had a lower body weight and were shorter in height than injured.</td>
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<td>Mota and Ribeiro.\textsuperscript{36}</td>
<td>Shoulder proprioception and shoulder</td>
<td>National league WP players</td>
<td>National</td>
<td>Players exhibited a negative correlation between proprioception acuity (absolute error) and peak eccentric ER torque at 30°ER (r= -0.505, Moderate correlation only, larger sample required for more robust analysis of</td>
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<td>Study Type</td>
<td>Strength</td>
<td>Age: 20.2±2.3y; n=20</td>
<td>p=0.023) The ER:IR strength ratio were 0.67±0.23 and 0.66±0.18, respectively for concentric and eccentric efforts. DCR was 0.69±0.16. Recommended value 1:1.</td>
<td>Correlation of proprioception and shoulder strength</td>
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<td>Klein et al.(^{14})</td>
<td>MRI abnormalities in shoulders of elite WP compared to controls</td>
<td>National WP league players Switzerland Age WP 23.9±5.1y, controls 30.9±4.0y. n=58; 28 WP, 15 control (30 shoulders) Elite WP players demonstrated significant change in subscapularis, infraspinatus tendon and posterior labrum (p=0.001, p=0.24, p=0.041). Other structures demonstrated no statistical difference including supraspinatous. All throwing shoulders showed abnormal findings in MRI but only 29% (n=8) were symptomatic.</td>
<td>Mean age of control 30y compared to 23.9y WP. MRI imaging instead of MRA, small control group numbers.</td>
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<td>Posture &amp; Shoulder Injury/Pain</td>
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<td>Gradidge et al.(^{30})</td>
<td>Posture and injury profiles of male high school water polo players</td>
<td>Male high school WP player Johannesburg Age 16.9±0.86y. n=36 males High School Good posture head, spine, abdomen (86%, 92%, 86%). Fair posture shoulder 81% and upper back 61%. All participants with previous Cx injury had poor abdominal posture and Lx posture. Of those with recent shoulder injury 66.67% had poor shoulder posture.</td>
<td>Adolescent population, results may be affected by developmental postural changes.</td>
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<td>Mukhtyar, Mahesh, Kaur.(^{27})</td>
<td>The effect of intense training on scapular kinematics of players with</td>
<td>Mumbai Residents with &gt;3yrs WP experience, training ≥ 10 sessions/week Sub-elite No statistically significant difference observed at baseline Post training comparison between injured and non-injured: 2D not 3D analysis, pool side measurement so impingement was diagnosed solely of clinical tests.</td>
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| and without shoulder pain | Age 17 – 35y. 
n=30 men; 16 non-injured, 14 injured WP | Injured athlete kinematics  
Scapular Abd was decreased at 45° and 90° humeral Abd (p = 0.0001, p = 0.008).  
RI decreased at 0° and 45° humeral Abd (p=0.0001, p=0.04). |

Abd = Abduction, Add = Adduction, AIS = Australian Institute of Sport, b/w = Between, CI = Confidence interval, Cx = Cervical spine, DCR = Dynamic control ratio ER = External rotation, FINA = International swimming federation, IR = Internal rotation, m= Months, L) = Left, Lx = Lumbar, MOI = Mechanism of injury, MRI = Magnetic Resonance Imaging, MRA = Magnetic Resonance Arthrogram, n = Number, NCAA=national collegiate athletic association, NS = Not specified, PROM = Passive range of motion, R) = Right, ROM = Range of motion, RI = Rotary index, WP = Water polo, y = Years, 90/90 = 90°abd 90°ER
### Supplementary material: Study quality evaluation

<table>
<thead>
<tr>
<th>Supplemental domain</th>
<th>Research question clearly defined</th>
<th>Appropriate study design</th>
<th>Population distribution described</th>
<th>Size of sample justified</th>
<th>Inclusion criteria defined &amp; applied uniformly</th>
<th>Exclusion criteria defined &amp; applied uniformly</th>
<th>Main measure valid and reliable</th>
<th>Main findings clearly described &amp; statistical significance reported</th>
<th>Described efforts to reduce bias</th>
<th>Main findings clearly described and statistical significance reported</th>
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<th>External validity discussed</th>
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<td>8.6</td>
</tr>
</tbody>
</table>

Note: + = Present, - = Absent.