Physical Therapy in Sport 40 (2019) 231–237

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

Reduced shoulder strength and change in range of motion are risk factors for shoulder injury in water polo players

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ARTICLE INFO

Article history:
Received 24 June 2019
Received in revised form
3 October 2019
Accepted 5 October 2019

ABSTRACT

Objective: To determine whether pre-season shoulder ROM and strength can be used to identify athletes at risk of future shoulder injury.
Design: Prospective cohort.
Setting: High performance sports institute.
Participants: 76 sub-elite water polo players.
Main outcome measures: Mean pre-season shoulder internal (IR) and external rotation (ER) ROM and strength values compared by gender, dominance and prospective injury status.
Results: 14-dominant shoulder injuries were recorded. There was a significant difference ($p = 0.05$) in total ROM difference (TROM) between the prospectively injured and no injury groups (−17.2°(30.4);-0.8°(13.3)), and dominant side ER strength (11.7%(2.4) vs 14.5%(2.8), $p = 0.03$) and IR strength (16.5%(3.0) vs 21.6%(4.9) as a percentage body weight (PBW) were also significantly different ($p \leq 0.03$). Separate significant associations were found between future episodes of shoulder injury and; dominant shoulder TROM difference of ≥7.5°(OR 3.6,95%CI 0.8–16.0), ER strength as a PBW≤12.5%(OR 5.2,95%CI 1.0–27.9), and IR strength as a PBW≤16.8%(OR 13.8,95%CI 2.2–88.0).
Conclusion: Pre-season dominant TROM difference, and reduced shoulder IR and ER strength relative to body weight were significant predictors for future shoulder injury. Although further investigation with a larger sample size is required, achieving optimal values on these measures may reduce future episodes of shoulder injury in water polo players.

1. Introduction

Participation in water sports is often considered low risk, however injuries are common, particularly to the shoulder region (Miller et al., 2017; Webster, Morris, & Galna, 2009). Water polo is a physically-demanding contact sport that requires athletes to perform repeated overhead movements. Multiple aetiologies have been proposed to contribute to the observed increased risk that these athletes have for shoulder pain and injury (Hams, Evans, Adams, & et al, 2019a, 2019b), including extrinsic factors such as repetitive throwing, swimming and withstanding forces applied from direct defensive contact with other players (Annett, Fricker, & McDonald, 2000). Intrinsic risk factors for shoulder injury in water polo also appear multifactorial. Deficits in proprioception, mobility and strength, as well as athlete gender, have been proposed as intrinsic risk factors that contribute to a water polo athlete's likelihood of experiencing a shoulder injury (Miller et al., 2017).

An optimal level of shoulder ROM, specifically shoulder ER ROM, is considered important for throwing proficiency, due to the increased available range/distance over which to ball acceleration can be achieved (Whiteley et al., 2010). In pain-free water polo athletes, increased dominant shoulder ER ROM (Elliott, 1993; Witwer & Sauers, 2006), and a corresponding loss of IR ROM (Elliott, 1993) have previously been observed. To date, however, no

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https://doi.org/10.1016/j.ptsp.2019.10.003
1466-853X/

association between shoulder injury and changes in shoulder ROM has been clearly established in the water polo literature.

In addition to the observed changes in shoulder ROM, and likely from their cumulated throwing volume, skilled water polo athletes also demonstrate a reduction in the relative strength of the shoulder external rotators compared to internal rotators in the preferred throwing arm (Bloomfield et al., 1990; McMaster, Long, & Caiozzo, 1991; Tsekouras et al., 2005). It has been proposed that this reduction in the relative strength of shoulder external rotators increases an athlete's risk of throwing-related injury, due to insufficient eccentric external rotator strength to decelerate the upper limb during the follow-through phase (Bloomfield et al., 1990; McMaster et al., 1991; Tsekouras et al., 2005). Whether these observed strength changes increase the risk of shoulder injury remains unclear, as the primary objective of most previous studies in the literature has been to develop normative data for the water polo population. No prospective injury follow-up has been previously considered for these intrinsic factors, and whilst changes in strength are considered to be sport-specific neuromuscular adaptations, there is currently no evidence that a change in the ratio of ER:IR rotator cuff strength leads to shoulder injury specifically in water polo.

Despite the high shoulder injury propensity in water polo (Hams et al., 2019a, 2019b), the descriptive nature of the current available literature limits the conclusions that can be drawn regarding intrinsic risk factors (Byram et al., 2010). Biomechanical research has indicated that the forceful water polo goal shooting action exposes the shoulder to similar torque to throwing in baseball (Feltner & Taylor, 1997; Wheeler et al., 2013). Thus, due to the similarities in the throwing motion, proposed risk factors for shoulder injury in water polo are often extrapolated from studies investigating shoulder injuries in baseball. It has been previously demonstrated in baseball that athletes presenting with a loss in throwing arm IR ROM and TROM have a higher risk of subsequent shoulder injury (Wilk et al., 2011). Further, athletes with insufficient ER ROM in the throwing shoulder (<5° greater than non-throwing) had 2.2 times the risk of developing a shoulder injury (Wilk et al., 2015). Pre-season ER weakness in baseball athletes has also been associated with increased in-season risk of throwing-related shoulder injury (Byram et al., 2010). Regardless of these similarities, this approach fails to recognise the unique physical requirement of throwing in water. The aquatic playing environment requires the water polo athlete to generate throwing force without a firm base of support, the athlete therefore is unable to transfer ground reaction forces through the body (Garrett & Kirkendall, 2000), reducing the contribution of the lower extremity to the kinetic chain (Miller et al., 2017). Although the baseball literature provides an evidence-informed foundation for clinical decision-making when working with athletes that play water polo, to enable targeted injury prevention programs and prevent recurrent shoulder injury, risk factors for injury specifically for water polo athletes need to be explored through prospective injury studies.

Based on the previous body of work from baseball, it is hypothesised that deficits in dominant shoulder TROM, IR ROM, ER gain and IR and ER strength may increase risk of shoulder injury in athletes who play water polo. The primary objective of this study was therefore to explore normative values for water polo players and whether pre-season shoulder ROM and strength values obtained at screening may be used to identify those athletes at risk of subsequent in-season shoulder injury.

2. Methods

Study design: This was a prospective cohort study involving all water polo athletes at one high performance institute. Australian water polo is decentralised, with each of the six states and two territories having a state institute or academy of sport water polo team from which the national team is selected. The athletes included in this study are hereinafter referred to as "sub-elite" as they were part of the wider group of athletes from which the national team is developed and selected.

The re-search pro-to-col was ap-proved by the Uni-versity of Can-berra Ethics Com-mit-tee (HREC15-221). To be eligible for inclusion athletes were required to be of a sub-elite water polo playing level. Athletes were excluded if they had a current shoulder injury, shoulder injury in the preceding 12 months that prevented them from participating in full unmodified team training, or if they had previously experienced a severe injury, such as shoulder subluxation/dislocation or surgery. At the pre-season musculoskeletal screening session, 4 weeks prior to the season, athletes were invited to participate in the study and signed an informed consent form regarding the release of prior musculoskeletal screening (2014–2015 season), and the gathering of subsequent 2015 injury data. Annual baseline measurements were completed again in 2015–2016 and 2016–2017 season for a new group of athletes and used to predict injury within the same season (12months period) for the corresponding group. Consent was gained before participating in the project.

Annual screening: Over a 3-year period, shoulder IR and ER ROM and shoulder IR and ER strength from 76 sub-elite level male and female water polo players was obtained annually pre-season by the team physiotherapist, from measurements made on a single data collection day. The athletes consisted of 28 male and 48 females with mean ages 19.8 (3.2) years and 18.8 (4.4) years respectively. See Table 1 for athlete characteristics.

Injury monitoring: All athletes who consented to participate were also monitored for injuries by the team physiotherapist. Injuries were recorded electronically using the SmartaBase Athlete Data Management system (AMS) (Fusion Sport, 76 Neon Street, Sumner Park QLD Australia 4074). An injury was defined as a musculoskeletal condition that required the athlete to receive physiotherapy treatment for the condition. All available physiotherapist treatment session records (n = 133) from 2015 to 2017 were coded and analysed for injuries by body area.

Shoulder ROM protocol: During the annual pre-season screening, passive shoulder ROM of both shoulders was measured using a TruMedical Baseline® bubble 360° inclinometer. Shoulder IR and ER was assessed with the athlete lying supine with their shoulder in 90° abduction, 90° elbow flexion and the forearm in neutral (zero position). No scapular movement was permitted. To ensure that the shoulder remained in contact with the plinth, it was stabilised anteriorly by the physiotherapist providing a posterior force to the anterior aspect of the athlete's coracoid process and acromion. For IR, the inclinometer was positioned centrally on the dorsal surface of the forearm, 2 cm proximal to the styloid process of the ulna. The testing position was reproduced for ER on the ventral aspect (Kevern, Beecher, & Rao, 2014). The dominant arm was assessed first and passively moved into both IR and ER. Rotation was performed until no further ROM could be acquired, the humeral head began to lift off the plinth, or the athlete reported pain. The angle was recorded in degrees, three trials were completed and the average taken. The TROM for the dominant and non-dominant arm was calculated by adding the athlete's IR and ER ROM together (Wilk, Meister, & Andrews, 2002), and glenohumeral internal rotation deficit (GIRD) and ER gain were calculated respectively by subtracting dominant IR ROM from non-dominant IR ROM (Wilk et al., 2011), and non-dominant ER from dominant ER ROM (Wilk et al., 2015). Neither the team physiotherapist nor the athletes were blinded to the ROM results. All athletes were measured by the same team physiotherapist to control

Table 1
Athlete characteristics. Mean (SD) for age and body weight and number of players by position and dominance.

		Female (n = 48)	Male (n = 28)
Age (years)		18.8 (4.4)	19.8 (3.2)
Body weight (kg)		78.6 (9.4)	86.1 (7.2)
Number of players by position	Goal keeper	7	5
	Utility	7	4
	Driver	14	12
	Centre Back	10	6
	Centre Forward	5	0
	Missing	5	1
Dominance	Left	5	4
	Right	43	24
	Missing	0	0

measurement error.

Shoulder strength protocol: Maximal shoulder IR and ER strength were measured using a JTech Medical, Powertrack II Commander hand-held dynamometer (HHD), with all measurements recorded in kilograms force (kgf). The athlete was required to sit on a plinth with hips and knees at 90° and feet flat on the floor. The arm was positioned so the elbow was against the body and the shoulder was at 0° abduction, elbow flexed to 90° and forearm in a neutral position. For IR, the dynamometer was positioned centred on the volar aspect of the distal forearm 2 cm proximal to the radial styloid, and on the dorsal aspect for testing ER. The athlete was instructed to "keep the elbow at your side, forearm parallel to the floor" to prevent abduction of the arm during testing ER. The physiotherapist was positioned on the same side as the shoulder being tested with two hands firmly holding the HHD. Athletes were instructed to produce a maximal contraction in a 5s make test, which the examiner met with equal and opposite force. Athletes were given a 5s rest between the three tests. If a breaking contraction occurred, the test was performed again (Dollings et al., 2012). Three trials were completed, and the mean taken. Absolute IR and ER strength in kgf and as a PBW were recorded. PBW was calculated by mean IR or ER strength divided by body weight (kg), multiplied by 100. The ratio of ER:IR strength was also calculated by dividing each athletes mean ER strength by their mean IR strength.

Statistical analysis: All statistical analysis was performed using SPSS version 23.0 (SPSS Inc., Chicago, IL, USA). The following ten variables were chosen as potential risk factors, due to their association with increased injury risk in baseball and proposed risk in water polo: TROM difference (dominant TROM − non-dominant TROM) (Wilk et al., 2011), dominant ER ROM (Elliott, 1993), GIRD (non-dominant IR ROM − dominant IR ROM), ER gain (dominant ER − non-dominant ER) (Wilk et al., 2015), non-dominant ER ROM (Whiteley et al., 2009a), absolute IR and ER (Byram et al., 2010) strength in kgf and as a PBW (IR or ER/body weight x 100) and ratio of ER:IR strength (ER/IR). (Berckmans et al., 2017).

The assumption of normality was tested for all analysis using Shapiro–Wilk tests, and found to be violated in the "injured" subgroup. For this reason, the Mann-Whitney *U* test was used to compare differences between shoulder strength and ROM data for water polo players who did and did not present with subsequent shoulder injury. Descriptive analyses were performed, including mean and standard deviation (SD) values for both the dominant and non-dominant shoulder ROM and strength variables. Independent t-tests were used to compared shoulder strength and ROM by gender. Individuals throwing and nonthrowing shoulders were compared with paired t tests.

Three measures were taken for both ROM and HHD and the mean taken. For measurement error and what might constitute true change, the standard error of measurement (SEM = SD x $\sqrt{1}$ − ICC was used to calculate the minimal detectable change (MDC_{95} = SEM x 1.96 x $\sqrt{2}$). (Weir, 2005).

Due to the small number of shoulder injuries and large number of potential risk factors, multiple-regression to determine relative contribution was not viable. Athletes were instead dichotomised as prospectively sustaining a "shoulder injury" or having "no shoulder injury", and independent groups t-tests were used to compare the means for the above selected variables between athletes who experienced a shoulder injury and those who did not. Statistical significance was set *a priori* at $p < 0.05$. Post hoc Bonferroni adjustment was not used due to the exploratory nature of the study (Bender & Lange, 2001; Perneger, 1998). Rather, to assess for association between potential risk factors and shoulder injury risk, optimal cut-off points on the ROC curve were determined for variables with differences in means that were significantly different on the independent t-tests ($p < 0.05$). The optimal cut-off on the curve was determined using the point where Youden's index was at its maximum, calculated as sensitivity + (specificity-1) (Biggerstaff, 2000). The global assessment of the performance of the test is determined by the area under the ROC curve (AUC) to indicate how well the strength and ROM variables under consideration discriminate between injured and uninjured players. AUC was interpreted as excellent (0.90–1.00), good (0.80–0.90), fair (0.70–0.79) or poor (0.60–0.69) (Altman & Bland, 1994). To explore the effect of a risk factor on the outcome of interest (shoulder injury), odds ratio (OR), positive likelihood ratio (LR+) and negative likelihood ratio (LR-), 95% CIs were calculated using contingency tables (Schmidt & Kohlmann, 2008). An OR of 1 was interpreted as indicating equal risk between groups and greater than 1 as increased risk (Andrade, 2015).

3. Results

Comparison of ROM by gender: There was no significant difference between males and females in ER ROM for either the dominant ($p = 0.69$) or non-dominant arm ($p = 0.83$). Female athletes had an overall greater ROM, displaying an average 8.5° ($p = 0.01$) and 7.0° ($p = 0.01$) more dominant arm and non-dominant arm IR ROM respectively. Female athletes also demonstrated 9.9° ($p = 0.03$) and 7.6° ($p = 0.04$) more dominant and non-dominant arm TROM than their male counterparts. The mean ER gain was 7.3° for male and 8.1° for female athletes and mean GIRD was for 12.0° and 10.1° respectively. TROM difference was 4.3° for male and 2.0° for female athletes, there was however no significant difference between these three measures by gender ($p > 0.50$). When male and female results were analysed together, there was a significant ER gain of 7.8° ($p < 0.01$) in the throwing arm compared to non-throwing arm, and a reduction of 10.7° ($p < 0.01$) in IR ROM,

with no significant difference in TROM ($p = 0.16$).

Comparison of ROM by dominance: The dominant/preferred throwing shoulder had significantly more ER ROM than the non-dominant shoulder for both male and female athletes. Dominant shoulder IR ROM was significantly ($p < 0.01$) less than non-dominant IR ROM. TROM was not significantly different between arms for either male ($p = 0.13$) or female athletes ($p = 0.49$). See Table 2.

Comparison of strength by gender: Male athletes were significantly stronger ($p < 0.01$) than their female counterparts on the dominant and non-dominant arm for IR, ER strength and strength as a PBW. No significant difference in strength ratio of ER:IR was found between genders ($p = 0.78$).

Comparison of strength by dominance: Compared with the non-dominant side, dominant shoulders were not significantly stronger for either ER ($p = 0.06$) or IR ($p = 0.23$). No significant difference in strength ratio of ER:IR was found between sides ($p = 0.07$). See Table 3.

Comparison of strength and ROM for prospectively injured and non-injured athletes: Non-parametric tests were conducted for each of the proposed intrinsic risk factors, to compare mean shoulder ROM and strength in athletes who developed a shoulder injury in their dominant shoulder over the next 12 months and those who did not. SD is presented in the parenthesis. Injured athletes' dominant arm GIRD displayed a loss of 17.8° (16.2), whereas non-injured athletes had a loss of 9.8° (12.7), with the difference not significant ($p = 0.13$). The ER gain of 8.7° was also not statistically significant ($p = 0.38$). See Table 4.

Three variables were found to be significantly different between athletes who prospectively developed a shoulder injury and those that did not, these being TROM difference (injured 17.22°(30.43), non-injured 0.81°(13.34), $p = 0.05$), dominant shoulder strength ER PBW (injured 11.7°(2.4), non-injured 14.5°(2.8), $p = 0.03$) and IR PBW (injured 16.8°(3.0), non-injured 21.6°(4.9), $p = 0.01$).

Injury group discrimination AUC for TROM difference was 0.70 ($p = 0.05$; 95% CI = 0.54 to −0.87), ER PBW AUC 0.76 ($p = 0.03$, 95% CI 0.59–0.93) and IR PBW AUC 0.82 ($p = 0.008$, 0.66–0.98), all showing good discrimination. Selection of cut-off values for maximum sensitivity and specificity showed an association between shoulder injury and dominant shoulder TROM difference of ≥7.5° (OR = 3.60, CI 0.82–15.98), ER strength as PBW ≤12.5% (OR = 5.20, CI 0.96–27.91) and IR strength as PBW ≤16.8% (OR = 13.75, CI 2.15–88.00). See Table 5.

Reliability of measures: The SEM and MDC_{95} derived from the mean of three ROM and strength measures varied from 0.41 to 0.72 (SEM) and 2.8°–3.9° (MDC_{95}) for ROM testing and from 0.8 to 1.4 (SEM) and 1.2kgf to 2.0kgf (MDC_{95}) for strength testing.

Injury type and associated time loss: Five injuries were sustained in the 2015 and 2016 season respectively, and four injuries were recorded in the 2017 season. Of these injuries two were classed as acute onset injuries from direct player contact, and 12 were classed as insidious in nature or overuse injuries. Of the 12 "overuse" injuries onset of pain was during pool training for nine injuries and the gym for the remaining three. The mean time for return to full unmodified training was 20.6 days (SD 19.6).

4. Discussion

The primary object of this study was to determine whether pre-season shoulder ROM and strength can be used to identify athletes at risk of future shoulder injury. The main findings were that sub-elite water polo athletes with a pre-season TROM difference of ≥7.5°, ER strength of ≤12.5% and IR strength ≤16.8% PBW have an increased likelihood of subsequent shoulder injury in the following 12 months. The MDC for the intra-rater analysis indicated that a change of ≥2.0kgf for the strength tests and ≥3.9° for the inclinometer ROM tests is required to be 95% certain the change is not the result of measurement error. This supports the clinical usefulness of the above strength and ROM threshold findings in identifying athletes during pre-season screening, who would benefit from targeted supplementary shoulder stretching and strengthening. Further to these primary findings, normative data for ROM and strength variables proposed to increase throwing athletes risk of subsequent shoulder injury were explored and similarities and differences of these findings are discussed below.

Shoulder ROM: In the current study, TROM difference of ≥7.5° was predictive of subsequent injury. Relative to those who had a TROM difference of less than 7.5°, players had 3.6 times the odds of an in-season shoulder injury. Our findings for TROM difference are similar to previous research in baseball, where a deficit exceeding 5° was a significant risk factor for injury (Wilk et al., 2011). Deficits in dominant IR ROM and TROM relative to non-dominant ROM have both been previously associated with shoulder injury risk in other throwing athletes (Chant et al., 2007; Whiteley et al., 2009b; Wilk et al., 2002). The descriptive findings of TROM difference and GIRD in this study indicate that it is typical for the sub-elite population to display an adaptive increase in dominant ER ROM and corresponding reduction in IR ROM. TROM is the athlete's combined shoulder ER and IR ROM. A shift in the TROM, whereby increased ER equals loss in IR ROM, has been previously demonstrated in other throwing sports (Whiteley et al., 2012), and TROM for both male and female athletes was also preserved in the current study. Loss of IR ROM is believed to be a normal phenomenon, and that a true pathological process occurs when TROM is not preserved and loss of IR exceeds gain in ER (Burkhart, Morgan, & Kibler, 2003). Although further prospective investigation is required, these findings suggest that when managing individuals who play water polo, in addition to standard shoulder ROM tests clinicians should consider monitoring athletes for a TROM difference in order to aid prescribing appropriate stretching interventions.

Table 2
Mean (SD) for shoulder range of motion in male and female sub-elite level water polo players 2014–2016.

ROM (°)	Non-dominant				Dominant				Non-dominant compared to dominant		
	Female	Male	Mean	Between gender (p)	Female	Male	Mean	Between gender (p)	Female (p)	Male (p)	Mean (p)
ER ROM (SD)	97.20 (7.66)	96.61 (13.06)	96.97 (10.05)	0.83	105.34 (15.63)	103.92 (12.12)	104.79 (14.28)	0.69	<0.01	<0.01	<0.01
IR ROM (SD)	58.95 (10.72)	51.96 (11.41)	56.20 (11.45)	0.01	48.84 (13.49)	40.36 (11.13)	45.49 (13.2)	0.01	<0.01	<0.01	<0.01
TROM (SD)	156.16 (9.87)	148.57 (16.76)	153.16 (13.44)	0.04	154.19 (19.66)	144.29 (16.87)	150.28 (19.12)	0.03	0.49	0.13	0.16

ER – external rotation, IR – internal rotation, PBW – percentage body weight, ROM – range of motion, TROM – total range of motion.

Table 3
Mean (SD) for shoulder strength in male and female sub-elite level water polo players 2014–2016.

	Non-dominant				Dominant				Non-dominant compared to dominant		
Strength (kgf)	Female	Male	Mean	Between gender (p)	Female	Male	Mean	Between gender (p)	Female (p)	Male (p)	Mean (p)
ER	9.32 (1.90)	13.19 (2.51)	10.80 (2.85)	<0.01	9.63 (1.47)	13.58 (2.45)	11.14 (2.70)	<0.01	0.23	0.13	0.06
IR	14.55 (2.82)	20.07 (3.73)	16.66 (4.17)	<0.01	14.33 (3.03)	21.22 (3.50)	17.00 (4.63)	<0.01	0.58	0.05	0.23
Ratio	0.65 (0.14)	0.67 (0.12)	0.66 (0.13)	0.71	0.69 (0.12)	0.65 (0.10)	0.67 (0.12)	0.16	0.15	0.30	0.46
PBW ER	11.96 (2.32)	15.99 (2.69)	13.62 (3.17)	<0.01	12.49 (1.87)	16.25 (2.71)	14.04 (2.91)	<0.01	0.25	0.42	0.16
PBW IR	18.36 (3.28)	23.81 (3.85)	20.61 (4.42)	<0.01	17.86 (3.31)	25.11 (3.81)	20.85 (5.01)	<0.01	0.27	0.10	0.56
Ratio PBW	0.67 (0.16)	0.67 (0.12)	0.67 (0.14)	0.78	0.71 (0.11)	0.65 (0.10)	0.69 (0.11)	0.07	0.15	0.22	0.48

ER – external rotation, IR – internal rotation, PBW – percentage body weight.

Table 4
Comparison between Mean (SD) pre-season strength and ROM measures for water polo players who prospectively developed a shoulder injury and water polo players who remained uninjured (2014–2016).

	Injured (n = 14)	Uninjured (n = 62)	Difference	Significance (p)
TROM difference (°)	17.22 (30.43)	0.81 (13.34)	16.42	0.05
Dominant ER ROM (°)	97.22 (21.67)	105.89 (12.76)	8.67	0.30
GIRD (°)	17.78 (16.22)	9.84 (12.67)	7.94	0.13
ER gain (°)	0.56 (21.71)	8.87 (11.47)	8.32	0.38
ND ER ROM	96.67 (6.61)	97.02 (10.50)	0.35	0.95
Dominant ER PBW (%)	11.7 (2.4)	14.5 (2.8)	2.8	0.03
Dominant IR PBW (%)	16.5 (3.0)	21.6 (4.9)	5.1	0.01
IR strength	14.60 (4.60)	17.31 (4.57)	2.71	0.09
ER strength	9.82 (2.35)	11.31 (2.71)	1.49	0.17
Ratio	0.70 (0.14)	0.67 (0.11)	0.03	0.63

ER – external rotation, GIRD – glenohumeral internal rotation deficit, IR – internal rotation, ND – non dominant, PBW – percentage body weight, ROM – range of motion, TROM – total range of motion.

Table 5
Sensitivity (Sn), specificity (Sp), and Youden's index (YI) for total range of motion (TROM) difference and external rotation (ER) and internal rotation (IR) as a percentage of body weight (PBW).

	Degrees	Sn	Sp	YI	OR (95% CI)	LR+ (95% CI)	LR-(95% CI)
TROM difference	−7.50	0.67	0.65	0.31	3.60 (0.82–15.98).	1.88 (1.06–3.33)	0.52 (0.20–1.33)
ER as PBW	12.49	0.57	0.80	0.37	5.20 (0.96–27.91)	2.79 (1.14–6.79)	0.54 (0.23–1.29)
IR as PBW	16.84	0.71	0.85	0.56	13.75 (2.15–88.00)	4.64 (1.94–11.1)	0.34 (0.10–1.10)

Sn – sensitivity, sp – specificity, YI – Youden's index, OR - odds ratio, LR+ – positive likelihood ratio, LR-negative likelihood ratio.

Dominant arm ER gain was observed in both male and female players. Interestingly, the mean dominant arm ER ROM 104.8° (14.3) in the current study was greater than in a previous water polo study that included male and female college level players 83.8° (10)[6] Although the athletes in both studies were of similar age, the difference in ROM may be due to the isolated glenohumeral technique used (Witwer & Sauers, 2006). Isolated glenohumeral ROM values are approximately 20° less than glenohumeral complex ROM values (Witwer & Sauers, 2006). Notably, the present values were similar to other overhead athlete studies conducted in elite swimming 105° (12) (Holt et al., 2017), handball 103.6° (8.9) (Myklebust et al., 2013), tennis 103.7°(10.9) and baseball 103.2° (9.1) (Ellenbecker et al., 2002), wherein athletes were stabilised anteriorly at the coracoid before being taken passively into ER and IR ROM.

The ER ROM gain observed in overhead athletes has been attributed to the demands of throwing (Whiteley et al., 2012). Increased ER ROM in the dominant arm has been associated with improved throwing performance, due to a longer available acceleration distance (Whiteley et al., 2010), and is proposed to confer reduced injury risk (Wilk et al., 2015). Similar to previous studies of water polo athletes (Elliott, 1993; Kibler et al., 2013), the current study, however, found no association between injury and dominant or non-dominant ER ROM. In adolescent baseball players, ER ROM in the non-dominant arm has been shown to be a predictor of injury risk (Whiteley et al., 2009a). The augmentation of available ER ROM is considered protective as it allows the athlete to achieve increased ER ROM before strain is transferred to soft tissue structures (Whiteley et al., 2009b). In the current study, when comparing athletes who developed shoulder injury and those who did not ER gain was not predictive of injury ($p = 0.38$). However, as a clinical guideline, descriptive data for uninjured sub-elite water polo players indicates that shoulder ER ROM greater than 100° is normal for this population (uninjured 105.9° (12.6) vs injured 97.2° (21.3), $p = 0.30$). Insufficient ER in the throwing shoulder in baseball has been demonstrated to increase risk of shoulder injury (Wilk et al., 2015). Therefore, given that ER ROM is a key mechanical component of the cocking phase of throwing required for successful performance in water polo, further prospective studies with a larger population are warranted to examine the role of sufficient ER ROM gain for throwing performance and injury prevention within this population before conclusions are drawn.

Shoulder strength: ER weakness has been previously shown to increase risk of subsequent shoulder injury in baseball (Byram et al., 2010) and handball (Clarsen et al., 2014). Absolute values for IR, ER strength and strength ratio, however, were not discriminators of injury risk in our findings. When strength was analysed relative to an athlete's body weight, ER strength cut off values of ≤12.5% and IR strength ≤16.8% PBW were associated with a respective increased likelihood of subsequent shoulder injury. No

relationship between IR strength and injury has been previously demonstrated in athletes that throw (Byram et al., 2010; Clarsen et al., 2014). In the current study, IR strength as a PBW was the stronger discriminator, whereby the odds of in-season injury for an athlete with reduced IR strength was 13.75 compared to ER strength whereby odds were 5.2.

Due to the shape of the osseous components of the glenohumeral joint, and resultant static instability, the surrounding muscles of the shoulder complex play an essential role in dynamic stability and injury prevention during throwing (Wilk, 1993). Water polo athletes require a delicate balance of IR strength for performance in throwing, swimming and defending, but also need sufficient ER strength to decelerate and dissipate force. A potential reason for the IR strength finding may be due to the combined overhead demands of the sport of water polo and unique aquatic environment. In water polo athletes generate throwing force without a firm base of support, reducing the contribution of the lower limbs to force summation (Colville & Markman, 1999). Furthermore, to avoid defensive contact, athletes will shoot from less than optimal ER, increasing the required IR velocity to achieve throwing success (Feltner & Taylor, 1997), and will physically block the opposing team in defensive play with their arms elevated (Colville & Markman, 1999). To ensure both optimal athlete throwing performance and injury prevention of the shoulder further investigation is warranted to confirm the current study's descriptive findings. In the interim the above cut-off values for shoulder strength as a PBW offer a clinical guideline for screening players preseason and provide a threshold for investing in supplementary shoulder strength training.

Although the strength ratio in this study was not significantly different for athletes who developed subsequent injury and those that did not, the authors however caution against disregarding strength ratios from current athlete clinical assessment, given the known role of relative ER strength in the deceleration of the upper limb in the follow-through of throwing. Furthermore, although beyond the scope of the current study, shoulder muscle endurance has also been proposed as a possible risk factor linked to overuse activities and the development of shoulder injury (Roy et al., 2011). Given the varied explosive and endurance actions involved in water polo, clinical assessment involving both muscle strength and functional endurance warrant consideration as an alternative testing approach.

Limitations: Although clinically useful, the above findings are limited by the hypothesis generating approach of this study. The small injury numbers, and uneven spread of male and female participants are a limitation of this study. Further, the exploratory nature of this current study and large number of comparisons reduces the statistical power of the findings. Other methodological limitations include equipment selection. HHD was utilised because it is a clinically accessible cost-effective alternative to isokinetic testing (Stark et al., 2011). However, isokinetic testing is considered gold standard over HHD as results are prone to error that may arise from the strength of the investigator relative to the athlete, different testing positions and the stabilisation of the athlete during testing (Stark et al., 2011). Although the decision to use clinically accessible measures may impact the reproducibility of results, this was somewhat mitigated by having the same physiotherapist perform all of the assessments.

The methodology was further limited by the decision to measure athletes in the neutral position. Given that the population of interest plays a sport with substantial overhead demand, the ecological validity of future testing could be improved through considering the use of a 90-90 testing position (Hams et al., 2019a, 2019b). Additionally, the decision to use isometric testing does not replicate the dynamic/eccentric ER component of throwing. Eccentric testing would provide a broader understanding of the athlete's strength profile with regard to their dynamic strength ratio (concentric IR:eccentric ER) and may build on the current understanding of shoulder strength ratio and injury risk.

Other limitations include the timing of pre-season measurements, it is plausible that for athletes that developed injury early in the season, their relative strength and/or ROM value may have been reduced by sub-acute injury. A recommended follow up study, would be to assess strength and ROM of athletes at various time points throughout the season to allow investigation into changes throughout the season. Results may have also been limited by selection bias and may not be generalisable to the wider water polo population due to inclusion of sub-elite athletes only. Future studies that include athletes across the age and performance spectrum should be considered. Despite the long history of the sport of water polo, literature regarding water polo specific injury risk factors is limited. The aim of this study was to explore proposed risk factor within water polo based on current evidence from baseball. However, the authors recognise that the decision to focus on strength and ROM in this instance is a limitation and that future investigation that includes assessment of shoulder proprioception, neuromuscular control and whole-body integration is required to build on an impairment-based model.

5. Conclusion

Water polo players demonstrate adaptive changes in strength and ROM in their dominant throwing arms. Three intrinsic and modifiable factors independently predicted subsequent shoulder injury; shoulder IR and ER strength as a PBW, and TROM, with IR strength as the strongest discriminator. These findings are likely explained by the repetitive demands of overhead throwing, swimming and defending. Until further prospective research is conducted, the continued inclusion of these variables in musculoskeletal screening is recommended, and GIRD, strength ratio and insufficient dominant shoulder ER ROM should also continue to be monitored.

Ethical approval

The research protocol was approved by the University of Canberra Ethics Committee (HREC15-221).

Declaration of competing interest

The authors have no financial affiliation or involvement with any commercial organisation that has a direct financial interest in any matter included in this manuscript.

Acknowledgements

The research team would like to thank the support of the Queensland Academy of Sport water Polo program and the Sport Performance Innovation and Knowledge Excellence Unit for their assistance with this project. Thank you also to Mr Adam Smith for his assistance with data collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.10.003.

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