The musculoskeletal profile of female adolescent elite water polo players and the factors affecting throwing performance.

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PLAGIARISM DECLARATION

I, *Lianne Verwey,* hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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LIST OF ABBREVIATIONS

AHD	Acromiohumeral Distance
APHV	Age at Peak Height Velocity
BMI	Body Mass Index
ER	External Rotation
ERG	External Rotation Gain
GH	Glenohumeral
GHER:GHIR	Glenohumeral External Rotator: Glenohumeral Internal Rotator Strength Ratio
GHJ	Glenohumeral Joint
GIRD	Glenohumeral Internal Rotation Deficit
GK	Goalkeeper
GM	Gluteus Medius
HAS	Hip Abduction Strength
HHD	Hand-held Dynamometer
IR	Internal Rotation
KC	Kinetic Chain
KJOC	Kerlan-Jobe Orthopaedic Clinic
LT	Lower Trapezius
N	Newtons
MRA	Multiple Regression Analysis
MTS	Maximal Throwing Speed
PML	Pectoralis Minor Length
RA	Rectus Abdominus
RC	Rotator Cuff
RF	Risk Factor
ROM	Range of Motion
SA	Serratus Anterior
SSA	Swimming South Africa
SWPSA	Schools Water Polo South Africa
TA	Throwing Accuracy
TP	Throwing Performance
TrA	Transverse Abdominis
TROM	Total Range of Motion
TS	Throwing Speed

USR	Upward Scapula Rotation
UT	Upper Trapezius
VAS	Visual Analogue Scale
WP	Western Province

GLOSSARY OF TERMS

Acromiohumeral Distance:	The distance between the acromion and the humeral head that is used to quantify the size of the subacromial space. It is usually measured radiologically with ultrasound, MRI or CT scans[1].
Adolescent:	A period of growth whereby one transitions from a child to an adult. Any individual between the age of 10-19 years[2,3].
Dominant:	An individual's preference for using one hand or foot over the contralateral side to perform functional activities[4].
External Rotation Gain:	An increase in glenohumeral external rotation range of motion in the dominant shoulder, compared to the non-dominant side due to a functional adaption[5].
Flexibility:	The ability of a muscle to lengthen without damage to permit increased range of motion at a joint[6–8].
Glenohumeral Internal Rotation Deficit:	A decrease in glenohumeral internal rotation range of motion the dominant shoulder, compared to the non-dominant side due to an adaptive response[5,9–11].
Maturation:	The process of physical growth during childhood[12,13].
Non-Dominant	An individual's preference for not using one hand or foot over the contralateral side to perform functional activities[4].
Overhead Athlete:	An athlete who partakes in a sport which requires a complex, overhead throwing motion that involves the whole body. An athlete who completes tasks that require repetitive, high speed, high load and increased range of motion with high accuracy[14]. It usually requires end range flexion, abduction, external rotation and horizontal extension of the glenohumeral joint[15]. Includes but not limited to throwers, swimmers, cricketers, baseballers, tennis players, handball players, water polo players etc.

Peak Height Velocity: A point at which an adolescent undergoes a maximal, rapid growth in stature during the growth spurt period. This term has been used to illustrate improvements in performance in relation to the growth spurt[12,16,17].

Preseason: The training period in sport prior to the start of a competition/match season [18–20].

Proprioception: The ability to sense joint movement in space without visual cues[21].

Risk Factor: A variable that potentially puts an athlete at risk of developing an injury/pain[18,22–24].

Rotator Cuff Muscles: The four shoulder muscles (supraspinatus, infraspinatus, subscapularis, and teres minor) that provide dynamic stability to the glenohumeral joint. They are responsible for shoulder elevation and rotational movements[25,26].

Scapula Dyskinesis: When the scapulae rest and move in an abnormal position and manner[11,14,27–31].

Strength: The capability of a muscle to endure a load[32,33].

Throwing Accuracy: The ability to throw an object (usually a ball) close to a desired target. Requires skill and motor control and is ruled by how faults at an object's projectile release are transmitted by flight dynamics[34].

Throwing Performance: Comprised of both Throwing Speed and Throwing Accuracy[35,36].

Throwing Speed: The projectile's speed at the point of release, whereby the release speed is proportionate to the mean force applied through the projectile's centre of gravity[37].

Total Range of Motion: The arc of glenohumeral rotational range of motion that includes total internal rotation range of motion plus total external rotation range of motion (in degrees)[38–41].

THESIS ABSTRACT:

The musculoskeletal profile of female adolescent elite water polo players and the factors affecting throwing performance.

Water polo is a popular water-based sport and a physically challenging game. Water polo demands extreme glenohumeral joint ranges of motion while throwing overhead, which is an entire-body movement requiring accuracy and precision. Water polo is unique as it loads the shoulder in four different ways, where players are required to swim explosively, pass and shoot the ball as well as wrestle with opponents and defend attempts at goal. A marked paucity of research exists regarding the factors affecting throwing performance in this vulnerable population. To date, there is also limited evidence on the musculoskeletal profile of female adolescent water polo players and whether it is comparable to that of other overhead athletes.

An overview of the literature (Chapter 2) describes the biomechanics of throwing in overhead sports, and the unique features of throwing biomechanics in water polo. Water polo players are required to throw from an unstable base of support and utilise an egg-beater kick which necessitates different kinetic chain contributions. Further, the parameters of throwing performance and the factors influencing it are discussed. While several studies have analysed musculoskeletal predictors of throwing performance in other overhead sports, very little is known about water polo, especially adolescent females. There are some common factors affecting throwing performance amongst overhead athletes, including anthropometric variables such as gender, age, height and body mass index, which all affect throwing speed and/or throwing accuracy. Range of motion of the glenohumeral joint, hip and knee joints as well as the thoracic spine have all been correlated with throwing speed in other overhead sports. Upper limb strength of the glenohumeral rotators, pectoralis minor muscle, wrist flexors, elbow extensors and grip strength have also been associated with throwing speed. Further, medicine ball throws also predicted throwing speed in cricket, handball and tennis. Lower limb strength in the form of hip abduction and abdominal strength as well as lower limb power were also found to influence throwing speed. There are also some unique variables to water polo which include extrinsic factors such as the presence of a goalkeeper, distance from the goalposts and different environmental conditions, which may affect throwing performance. The musculoskeletal profiles of overhead athletes appear to share features, but there are also unique variables seen in the different overhead sports. Water polo players do not appear to follow the typical 'thrower's paradox' described for baseballers. Instead, they are found to largely preserve their glenohumeral internal rotation range of motion and have lower glenohumeral external to internal

rotator strength ratios. Therefore, the musculoskeletal variables found amongst baseballers are unique and cannot be directly extrapolated to other sports, including water polo. The musculoskeletal profile of female adolescent water polo players and the relationship between these variables and throwing performance have not been well described in the literature.

Chapter 3 is the research chapter and describes the musculoskeletal profile of female adolescent water polo players and the musculoskeletal contributors to throwing performance in this population. Age group related changes in musculoskeletal variables and side-to-side asymmetries were investigated. There were three steps in the data collection process. Firstly, informed assent/consent and basic demographic information was obtained after participants had been selected for a regional representative team. Participants completed the Kerlan-Jobe Orthopaedic Clinic questionnaire to assess shoulder functionality. Secondly, a battery of musculoskeletal screening tests was conducted. Anthropometry, pain-provocation tests (Hawkins/Kennedy, Empty Can and Full Can), glenohumeral rotational range of motion, upward scapula rotation, scapular and glenohumeral strength measurements, pectoralis minor length and medicine ball throw tests were included. Finally, participants performed throwing speed and throwing accuracy tests in the pool which were measured with a radar gun and the number of targets hit, respectively.

All the collected data was grouped together and analysed using SPSS 28.0 (IBM, Armonk, New York, USA). The condition for statistical significance was set as $p < 0.05$. For the statistical analysis, throwing speed and throwing accuracy were considered the dependent variables while the rest were the independent variables. The Shapiro-Wilk test was performed to assess normality of data, and descriptive statistics were calculated for all variables. Throwing speed and throwing accuracy were found to not be normally distributed ($p < 0.05$) and a bivariate Spearman's correlation was used to test for linearity. Multi-collinearity was tested for, to investigate inter-variable correlations. Homoscedasticity of the multiple regression analysis model was determined by fitting a Loess curve to the scatter plot of standardised residuals and standardised predicted values.

Eighty-three female water polo players between the ages of 14 and 18 participated in this study. This population presented with low shoulder-functionality Kerlan-Jobe Orthopaedic Clinic scores and the musculoskeletal profile was described as follows; an external rotation gain was observed, while participants appeared to largely preserve both glenohumeral internal rotation range of motion and total range of motion. They presented with a downwardly rotated scapula at rest, but this rotation increased at 45°, 90° and 135° of glenohumeral abduction as well as a shorter pectoralis minor muscle on the dominant side. A significantly stronger lower trapezius muscle was noted on the dominant side compared to the contralateral side. Participants had fairly symmetrical internal and external rotator strength scores, with a strength ratio of 0.8. The mean throwing speed value was 23.7 ± 6.7 mph and there was a consistent improvement in throwing speed across the age groups. Throwing accuracy was consistently poor for the group with an average target accuracy of 28.8%. Prior to the multiple regression analysis, age group, dominant pectoralis minor length, non-dominant pectoralis minor length, dominant upper trapezius strength, non-dominant upper trapezius strength, dominant serratus anterior strength, dominant upward scapula rotation at 135° and non-dominant upward scapula rotation at 90° were all significantly correlated with throwing speed. Sitting height, dominant glenohumeral internal rotation range of motion, dominant upper trapezius strength, non-dominant upper trapezius strength and dominant serratus anterior strength were all significantly correlated with throwing accuracy. However, after the multiple regression analysis, age group was found to be the only significant predictor of throwing speed, while dominant glenohumeral internal rotation range of motion was the only variable to significantly affect throwing accuracy. Between the age groups, significant differences were noted for scapula muscle strength (serratus anterior, upper trapezius and lower trapezius), upward scapula rotation at 0°, 90° and 135°, pectoralis minor length, non-dominant glenohumeral external rotator strength as well as medicine ball throws. Furthermore, participants also presented with significant side-to-side asymmetries in glenohumeral rotational range of motion and lower trapezius strength, but displayed very few other asymmetries typically described in overhead throwing athletes.

By understanding musculoskeletal profiles of female adolescent water polo players and performance parameters, coaches, trainers and clinicians will be able to consider factors that affect throwing speed and throwing accuracy to enhance the individual water polo player's throwing performance, while simultaneously being aware of the potential risk of injury in this group. This study adds to the limited current body of literature on the musculoskeletal profile of female adolescent water polo players, specifically South African players, and how these factors may influence throwing performance.

CHAPTER 1: INTRODUCTION AND SCOPE OF DISSERTATION

1.1 Introduction

Water polo, a fast-paced aquatic team sport, has its roots in England in the 1860's and was considered an aquatic proxy for rugby during the summer off-season[42,43]. It is the earliest team sport to form part of the Olympic Games[44] and is one that is growing in favour[45], becoming increasingly popular[46]. The aim of the game is to score more goals than the opposition which is done by shooting a ball, weighing 450g, into a goalpost, measuring 3 X 0.9m, at the edge of the swimming pool, which is 30 X 20 X 1.8m in dimension. A waterpolo match is typically 32 minutes long and divided into four quarters of eight minutes each[42,47]. In South Africa, water polo is governed by Swimming South Africa (SSA) and Schools Water Polo South Africa (SWPSA). At competitive level, it attracts a large rate and range of injuries, with a large number of shoulder injuries sustained during competition[48].

It is known that water polo athletes require adequate shoulder range of motion (ROM), especially end range glenohumeral (GH) abduction and external rotation (ER) ROM[49], for optimal throwing performance (TP). Players are required to generate large forces and an increased rotational GH ROM is advantageous to achieve this[39], and may be associated with greater ball speeds. This places an increased load on the shoulder complex as it is responsible for the adequate distribution of forces[50]. Throwing speed (TS) in water polo ranges between 26.01 mph[51] and 37.1 mph[52] and appears to be substantially slower compared to land-based sports such as baseball, cricket, tennis and handball where values range between 30.4 mph[53] and 82.1 mph[54]. This is likely due to the unstable aquatic base that athletes are required to shoot from.

Studies have found that a myriad of factors affect TP, comprising both TS and throwing accuracy (TA), across the overhead sports, and include various anthropometric variables[55–72]. Musculoskeletal variables in overhead athletes such as ROM[70,73–77], GH rotator strength[67,70,72,78–84], grip strength[61,62,71,83,85,86] and both upper body[63,64,70–72,79,87–89] and lower body power/strength[35,58,79,90–93], amongst others, have also been found to impact TS.

In water polo specifically, players' abdominal stability[89,94] and pectoralis minor strength[89] positively impacted TS. Additional factors influencing TS or TA include proprioception[50,95] and fatigue[51,96,97]. Various extrinsic factors such as workload[20], environmental conditions[98], the presence of a goalkeeper (GK)[52], distance from the goalposts[56] as well as training age[99] and programmes[100] were found to predict both TS and TA in water polo in particular.

Overhead biomechanics appear to be different amongst various overhead sports. Dutton et al., (2020)[101] found the throwing biomechanics of cricketers to be different to that of baseballers. Further, cricketers presented with an 'atypical thrower's shoulder' with a distinctly different musculoskeletal profile to baseball pitchers[102]. In athletes who are required to throw overhead, the dominant upper limb should have a delicate balance between stability and mobility to ensure optimal performance[38]. However, the dominant upper limb has been shown to exhibit changes in movement patterns in a variety of sports including baseball, tennis, swimming as well as water polo[103]. These alterations include hyper or hypo-mobility and are thought to arise from structural changes within the shoulder complex over time[103]. For these athletes, the shoulder is a balancing act between having enough stability to prevent the joint from subluxing, while also having enough flexibility or range to throw effectively overhead. This is known as the 'thrower's paradox'[38.]. However, very limited evidence exists regarding the musculoskeletal profile of a water polo player and whether they present similarly to other overhead athletes, given the distinct biomechanical differences in the water polo throw. There is even less evidence regarding the factors affecting TP in waterpolo, especially amongst adolescent females.

Screening for musculoskeletal deficits in ROM, strength and flexibility prior to a competition season has been shown to be beneficial to identify various risk factors (RFs) in other sporting populations including football[104], volleyball[104] and running[105]. Once these factors have been identified, clinicians can design and implement an intervention programme aimed at modifying these factors, with the ultimate goal of reducing shoulder pain and improving TP. However, there is inadequate evidence regarding the factors that affect TP in water polo and whether these are comparable to other overhead sports such as cricket, swimming, baseball, and tennis.

Overall, there is limited evidence on the relationship between musculoskeletal factors and TP in female adolescent elite water polo players, as very few studies have assessed TS and TA amongst this population. Furthermore, there is a high risk of shoulder pain amongst adolescent water polo players due to the nature and demands of the game[43,106–109], which could be attributed to swimming[103], defensive wrestling[110] and overhead throwing[39,111]. Worldwide, an incidence of 38-80% has been recorded for musculoskeletal shoulder pain amongst water polo players[110]. This can negatively affect an athlete's TS, TA and ultimately, TP.

Purpose statement

The broad intention of this research project is to describe the musculoskeletal profile of female adolescent elite water polo players and to identify the musculoskeletal factors affecting TP.

1.2 Aims and objectives

1.2.1 Aim

The primary aim of this study was to describe the musculoskeletal profile of female adolescent elite water polo players in South Africa and to identify the factors affecting TP amongst these athletes.

1.2.2 Specific objectives

The specific outcome measures of the study were:

a. To describe the musculoskeletal profile of female adolescent elite water polo players and compare this profile to that of other overhead athletes.
b. To investigate the influences of these different musculoskeletal variables on both throwing speed and throwing accuracy amongst female adolescent elite water polo players. A novel throwing accuracy measure was introduced to assess this parameter of throwing.
c. To describe the musculoskeletal parameter changes from U14 to U19 in a group of female adolescent elite water polo players.
d. To explore the side-to-side asymmetries amongst female adolescent elite water polo players.

1.3 Plan of development

In order to further explore this topic, a detailed literature review of the factors affecting throwing performance, amongst different overhead sports is presented. The different musculoskeletal profiles of a baseball pitcher, water polo player, swimmer, cricketer, tennis player and handball player are described. Current evidence on the factors affecting TP in overhead athletes is presented (Chapter 2). This provided a groundwork for the cross-sectional quantitative cohort study investigating the musculoskeletal profile of female adolescent elite water polo players as well as the factors affecting throwing performance, in South Africa (Chapter 3). Finally, the findings of the study and the associated implications are reviewed and summarised (Chapter 4).

CHAPTER 2: A REVIEW OF THE LITERATURE

2.1 Introduction

Water polo is now played in many countries worldwide[112] by both males and females as well as people of all ages. It is described as both a physically and mentally challenging sport[42,43,113]. There are great stresses placed on the upper extremities of the water polo player, given the game's explosive sprints of fast swimming[103], the requisite directional changes every 6.2 seconds[114], defensive wrestling with opposing players[110] and the continuous passing and overhead shooting of the ball[39,111,115]. This may account for the high rates of shoulder injuries seen amongst adolescent water polo players specifically[106].

Importantly it is the scoring of goals that secure wins and thus, TP is key to the game. The factors that affect and predict TP, appear to differ between overhead sports, with some having a positive influence, while others may negatively affect TS and TA. It is becoming increasingly clear that not all overhead athletes present with the same musculoskeletal profile, due to distinct biomechanical needs, such as water polo having an unstable base of support[106] when compared to baseball[116].

To date, there is limited evidence on the musculoskeletal profile of water polo players and the relationship to TP in adolescent elite water polo players, more especially female adolescents. The aim of this literature review is to explore the research on the musculoskeletal profile differences between overhead athletes in baseball, water polo, swimming, cricket, tennis and handball. Furthermore, we aim to identify the musculoskeletal factors that affect TP.

2.2 Design

This literature review adopted a narrative review design as there is limited scientific evidence on the musculoskeletal profile of adolescent water polo players and its influence on TP. A peer-reviewed literature search was done using PubMED, Google Scholar, Web of Science and EBSCO Host (Academic Research Premier, CINAHL, Health Source – Consumer Edition, MasterFILE Premier and MEDLINE). The following variation of search terms were used: 'water polo', 'water polo players', 'waterpolo athletes'; 'throwing performance', 'throwing speed', 'throwing accuracy'; 'adolescent', 'provincial water polo athletes', 'western province water polo', 'provincial water polo players', 'elite water polo players', 'female water polo players'; 'South Africa', 'SA'; 'intrinsic risk factors', 'risk factors', 'shoulder pain', 'musculoskeletal profile', 'musculoskeletal factors'. Other key terms that were used are: 'prevalence', 'incidence', 'epidemiology', 'swimming', 'overhead sport', 'adolescent', 'swimming', 'throwing', ‘shooting’, ‘water polo biomechanics’ for information on biomechanics in water polo and injury risk. Another search was done using the following terms for information on factors affecting throwing performance in the overhead athlete: ‘swimming’, ‘baseball’, ‘cricket’, ‘handball’, ‘tennis’, ‘throwing load’, ‘factors affecting throwing performance’, ‘factors affecting throwing speed’, ‘factors affecting throwing accuracy’. Only articles in English and with access to the full text were included. Randomised controlled studies and those published after the year 2000 were given preference, however relevant articles predating this period were also included.

2.3 The shoulder in overhead athletes

2.3.1 The shoulder complex

The shoulder is made up of a variety of different structures, including three bones and four joints namely the humerus, clavicle, scapula and the GH, sternoclavicular, acromioclavicular and scapulothoracic joints, respectively[25,117]. The ball and socket joint of the shoulder allows for greater ROM which facilitates activities like overhead throwing but introduces inherent instability that may increase the risk of injury. Shoulder stability is determined both by the static and dynamic systems of the GH and scapulothoracic joints[25,118,119].

The shoulder’s static stability is provided by the joint capsule, articular surfaces and surrounding ligaments. These non-contractile structures act to stabilise the joint as it moves towards the end of its ROM[25,117]. Dynamic stability is provided by the primary stabilisers which consist of the rotator cuff (RC) muscles (supraspinatus, infraspinatus, teres minor and subscapularis), as well as the secondary stabilisers which are the long head of the biceps, pectoralis major, latissimus dorsi and teres major[25,26]. These contractile structures act to stabilise and move the GH joint (GHJ)[117,118] while keeping the head of the humerus centred within its fossa[25,26,120]. When the shoulder is moved into a position of elevation and abduction (as in overhead throwing) by the deltoid muscle, the humeral head moves superiorly towards the coracoacromial arch[119,121]. To counteract this, the RC muscles co-contract, keeping the head of the humerus centred within the glenoid[29]. All these structures need to work together symmetrically[25,31,122] and synchronously to ensure that the humeral head remains centred and that the length-tension relationship of the RC muscles is maintained. The scapula also moves into a position of upward rotation, ER and posterior tilt[123] during shoulder abduction, to ensure both static and dynamic stability of the shoulder.

To perform effectively, a balance between stability and mobility in the dominant shoulder of the overhead throwing athlete is deemed necessary[38]. The ‘thrower’s paradox’ describes a shift in the arc of GH rotational movement, known as total range of motion (TROM), towards maximised GH ER ROM[38], leading to a subsequent decrease in GH internal rotation (IR) ROM, whilst still maintaining a TROM of 180°[124]. This adaption has been positively linked to TS in the overhead athlete[125,126].

Muscles all work in force couples to regulate the movements of the scapulae when the upper limb is elevated[127,128]. The scapulae need to move with the clavicle into a position of elevation, abduction and posterior tilt. This is important so that the coracoacromial arch can be elevated away from the RC insertion on the greater tuberosity of the humerus in a position of abduction[29,30]. This requires an integrated recruitment of muscles controlling the scapula[25,29,31,103,122,127–132]. Scapulohumeral rhythm can be affected if there is an alteration in the position of the scapulae as this may lead to an increased load on the shoulder structures[27,29], possibly jeopardising TP.

2.4 Biomechanics of overhead sport throwing

Research has investigated the complex throwing action of many overhead sports, with numerous studies on baseball[133,134], handball[63,135] and cricket[75,79,101,102,136,137]. For the effective overhead land throw, energy is generated by the lower limbs and the trunk and then transferred along the kinetic chain (KC) to the shoulder, elbow, hand and then ultimately the ball[133,138]. The biomechanical phases of these sports are the windup, stride, cocking, acceleration, deceleration/follow-through[133,134]. Abduction and maximal ER of the shoulder is quickly attained, followed by maximal GH IR, exerting great forces and torques on this joint, with concomitant high angular velocities[134].

Sport-specific demands, necessitate how these phases are executed, compared to the conventional baseball model, resulting in some differences in throwing techniques being observed in different throwing sports. These differences in biomechanics appear to be reflected in differences seen in the musculoskeletal profile of different overhead athletes[102]. When compared to the gold-standard of the 'thrower's paradox' seen in baseball[38], there is a greater GH ER ROM and then faster GH IR ROM with nominal observable variations in shoulder flexion or abduction for handball players. The conventional proximal-to-distal order is not followed and it is the elbow that first reaches maximal speed followed by the shoulder[135]. When compared to baseball players, cricketers adopt a greater sidearm throw and have less GH ER and less flexion of the thorax[102]. In addition, various overhead sports have differing time-stress requirements, such as the need for a speedy throw from the boundary to the wicket, which is absent in the baseball pitch[137.] This mirrors the urgency required to pass and shoot quickly in water polo, given the defensive pressure exerted by opponents.

2.4.1 Water polo biomechanics

The biomechanics of the water polo throw appears to incorporate the recognisable throwing motion of the baseball pitch[68,139,140]. However, there are additional challenges for the water polo player as they need to wrestle opponents and control, pass and shoot the ball, while remaining buoyant in water[39,110,111,115]. Thus, while the overhead water polo throw shares some commonalities with similar overhead sports, many of the biomechanics of this water sport throw are distinctively different to the land-based sports. In contrast to land-based throwing sports, body weight is reduced in water[115] and importantly, given the lack of a traditional fixed point from which to perform hip and trunk rotation, the player utilises the distinctive egg-beater kick which serves to provide a quasi-base[68,116,140]. This kick balances the player, allowing a fast and accurate throw[112,141]. The key variance, therefore, is the lack of the conventional support base that would normally facilitate power production[116,142], resulting in a differing relative contribution of the traditional proximal-to-distal KC throwing sequence[116]. Alexander, Hayward and Honish's (2010)[116] seminal work cited in many studies on the biomechanics of water polo throwing, postulated that in water polo, the trunk turns as one unit, whereas in the baseball pitch, a more effective three-segmented rotation occurs. The baseball pitch begins with the hips, continued by the middle-trunk and finishing with the shoulder girdle, resulting in a more proficient proximal to distal biomechanical segmental chain energy transference[116].

In water polo, the lower limbs are not as efficient in producing energy, resulting in more stress being placed on the distal components in order to shoot effectively[40,43,116,142,143]. Whilst the lower limbs and the non-dominant upper limb generate a continuous downward force through the water, providing the lift force necessary to elevate the player above the water[116], the trunk of the water polo player generates only 30-50% of the force that contributes speed to the throw, which leaves distal segments, like the shoulder, to generate more speed[144]. Despite average ball velocity in water polo being slower than baseball[56,61,90,139], throwing forces on the shoulder are similar[145].

Given the various types of overhead activity seen in a game of water polo, multiple throwing techniques are employed by water polo players, influenced by their position in the play field or their own body position upon either passing or shooting[94,116]. However, shooting for goals is essential to winning the game[139,146] and various shooting techniques are employed such as the overhead throw, back, push and penalty shots in an attempt to score goals[147,148]. The overhead throw is most successful in scoring goals, when compared to the back shots and push shots, given its speed and accuracy[148,149], most likely due to its effective implementation of a greater number of segments in the KC principle[147]. It was reported that the penalty shot, using the overhead throw, enjoyed a success rate of between

77% and 80.1%, and impacted the outcome of 20% of analysed games[150,151]. The push and back shots are viewed as more tactical in nature[116,148].

2.4.2 Phases of the water polo throw

The overhead throw, back shot and push shot all move through the same phases[147] (Table 2.1). They begin with the preparatory phase wherein the ball is elevated out of the water. This is followed by the backswing, where dominant arm rotation is achieved by hip and shoulder rotation. This leaves the ball in a position of elevation, above and to the rear of the head. The trunk is required to move from a position of extension into forward flexion, while the shoulder moves into a position of maximal ER[116]. This phase accrues potential energy[116]. The forward swing commences activating the proximal-to-distal chain[152], with potential energy transferred into kinetic energy through the shoulder, elbow then hand, thereby increasing speed, and finally the release, where the ball is discharged at the greatest speed in the direction of the goal[148]. The non-dominant arm is used to scull the water, thereby ensuring both stability and upward drive[152]. It is the resultant momentum and speed achieved by each kinetic link that determines the speed of the throw[116,148].

Table 2.1: Biomechanics of the water polo throw phases

Shooting Phases	Biomechanics	Muscle Activation
Preparation and Backswing  	*Preparation* - Hips angled 45-90°, facing goals[116] - Dominant shoulder slightly abducted and externally rotated[116] - Player's dominant hand places downward pressure on ball[153] - Ball elevated slightly out of water[116,153] *Backswing* - Player lifts themselves above water utilising strong egg-beater jump[116] - Force translated along KC to ball[116] - At max height, trunk and hips rotate[94,116,] moving dominant shoulder (and arm with ball) opposite to goal and non-dominant hip and shoulder perpendicular to goal[116,134,153] - Once trunk rotated, dominant shoulder abducts and externally rotates[116] - Elbow flexed to lift ball and the wrist and fingers are extended[116,134] - Shoulder in max ER and elbow flexed (80-100°) and ball is elevated above and behind head[116,148,153] - Non-dominant shoulder to have an abduction angle of > 90°, with the arm aimed at goal[116,154]	- Continuous activation of the core muscles throughout phase to stabilise[116] - Unilateral contraction of obliques, rectus abdominis (RA), transversus abdominis (TrA) and multifidus[94,116] - Abduction = supraspinatus and deltoid[29,116,134] - External rotation = infraspinatus and teres minor[116,122,134] - Serratus anterior provides stabilisation[147,153]
Forward Swing  	- Initiated by trunk rotation, moving dominant arm in direction of goals[116] - Trunk also then moves from hyperextension to forward flexion to produce more energy[116] - Trunk rotation aided by non-dominant shoulder moving into horizontal abduction and extension, forcing dominant shoulder into further ER, also to produce more force[116] - Forward motion of dominant arm commences with horizontal adduction followed by GH IR[116,134] - Elbow moves into 150° of extension upon ball release[116] - Throwing arm moves in arc-like motion and trunk flexes away[116,142]	- Unilateral contraction of obliques, RA, TrA and multifidus[116,155] - Pectoralis major and anterior deltoid plays an important role in shoulder moving from full ER into horizontal adduction[121] - Horizontal adduction = pectoralis major[116,147]; internal rotation = subscapularis and latissimus dorsi[116,134]

Ball Release 	- Trunk moves into forward flexion[116] - Elbow moves to extension and wrist into flexion[116,156] - Non-dominant shoulder moves to side of body[94] - Dominant shoulder abducts to 90° and elbow extended to 180°[116,153] - Forearm pronates and wrist flexes to increase TS[116] - Ball released with shoulders parallel to goals and trunk forward[116]	- Simultaneous contraction of obliques, RA and TA bilaterally[116,155] - Shoulder abduction = supraspinatus and deltoid[29]
Follow-Through 	- Dominant shoulder still in horizontal adduction and GH IR, elbow extension, forearm pronation and wrist flexion[116] - Posterior shoulder stressed in max GH IR[134] - Shoulder IR and horizontal adduction = to increase TS[116,147,148] - External rotators contract eccentrically[134] - To slow down horizontal adduction of dominant arm, long head of biceps tendon is stressed[144]	- ER = infraspinatus and teres minor[134]

2.4.3 Swimming biomechanics

In contrast to conventional swimmers, water polo players are required to alter their swim speed, direction as well as the types of stroke[157] in order to accommodate the demands of the game that involve defending against and attacking opponents[44]. They use three different freestyle strokes: conventional head-down freestyle, a modified head-up freestyle, and head-up freestyle whilst leading the ball[157]. The utilisation of the conventional freestyle stroke enables rapid movement across the pool during a water polo game, whilst employing the adaption to a head-up freestyle stroke, allows for observation and the maintenance of ball possession[42,43,113,143]. This adapted head-up swimming stroke results in an extended cervical spine, shorter but more frequent swim strokes, and exaggerated arm elevation to keep the ball in front of the player, which all loads the GHJ[42,157,158]. The scapula protraction, which usually occurs prior to the body roll in conventional freestyle swimming, is eliminated, thereby increasing shoulder abduction and IR with concomitant greater loading of the RC muscles[143,159]. Given that the swimming action takes place at a continuous, but albeit lesser angular velocity, many more repetitions of the head-up swimming stroke are performed, compared with the throwing component of the water polo game[115,160].

2.5 Throwing performance

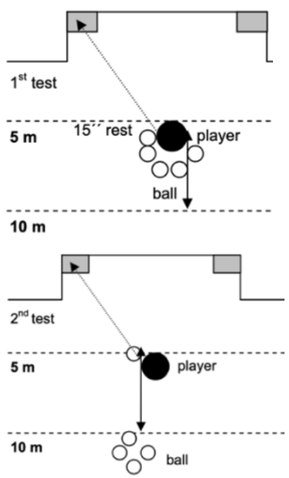
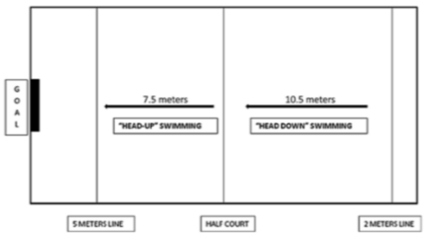
TP, a combination of both throwing speed (TS) and throwing accuracy (TA)[36], is multifaceted and requires many different joint motions which result from interactions between different variables[133,134]. The KC and the co-ordination between the proximal and distal body segments plays a vital role in TP as well as in the adequate and even distribution of forces[133,134]. Additional variables such as cognitive[161] and sensorimotor control[162], shoulder proprioception[50] and levels of anxiety[163], also influence TP.

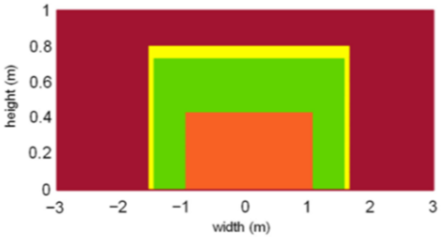
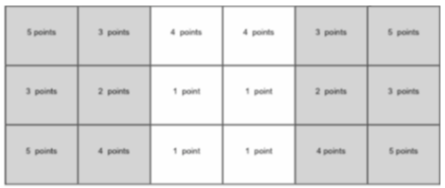
Many studies have investigated TP in baseball[69,73,74,90,92,95,97,164–166], handball[53,59,63–65,80,85,86,167,168] and tennis[70–72,76,77,81,83,84,87,88,93,169–177]. However, there is limited evidence available about the different musculoskeletal factors that may play a role in TP amongst other overhead sports such as cricket[35,75,79] and more specifically water polo[61,62,67,78,89,91,94,178]. There is a particular paucity of studies investigating these factors in adolescent[94] and female water polo players[67,78,178].

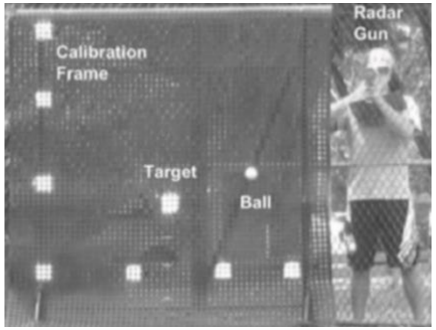
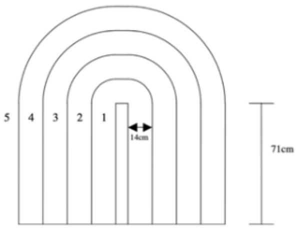
Various tests are used to assess the functioning of the KC as well as predict throwing speed and accuracy (performance). It has been found that tests which mimic both the movement and speed of throwing, are good predictors of TA[79]. Tests such as the 'lateral to medial jump' and 'medicine ball rotation throw', which require synchronisation and involvement of various portions of the KC, were shown to be correlated to TS amongst cricketers[79]. Smaller body segments involved with the overhead throw can be assessed separately, in attempt to pick up any deficits along the KC that may need intervention[179].

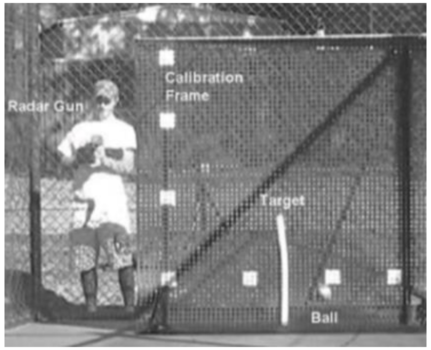
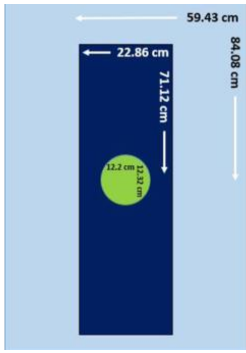
While measuring TS is quite straightforward and is commonly done with a radar gun calibrated to mph, km.h or m.s^{-1}, assessing accuracy is more complicated. This is largely due to multiple different scoring systems being used across the literature (Table 2.2). Some set-ups are basic, using a simple targets[96,168,180–182], while others are more complex and include self-designed targets specific to that sport[35,55]. The points awarded for targets hit or missed, differs between studies, with some studies awarding more points based on the likelihood of the target being struck[183], with others awarding them depending on how close they were to the centre[35,55,59,96]. This makes comparison of accuracy results very difficult as no standardised tool has been established.

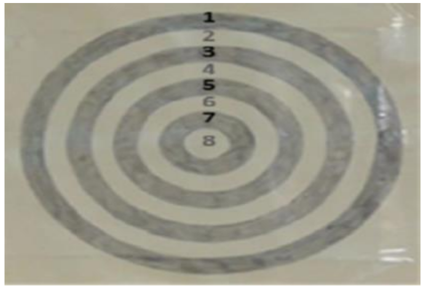
Table 2.2: Summary of studies assessing TA amongst different overhead sports

Study	TA Score	Population	Methodology
Water polo			
Platanou and Botonis, 2010[99] 	Average accuracy score ranged from 35-80% for static position shooting and from 11.7-53.3% for previous swimming shooting. Results varied depending on training age, which ranged from 2-8 years (increased training age = increased accuracy).	Adolescents. Aged 11-17 years. ***Gender and mean age not specified**	*Test 1*: Participants required to perform 5 shots from a static position after previous sprint swimming from 10 m to 5m away from goalpost with 15 sec rest between shots at a pre-designed target. Goals had been placed in the 2 corners (top left and top right) of goalpost. Dimensions were double the size of ball's diameter. *Test 2:* Players then performed 5 more shots after swimming 10m away from goalpost and stopped at 5m for shooting. Participants started swimming with the ball from the 10m to 5m mark with no interval time between shots, and then returned back at 10m to repeat.
Stevens et al., 2010[51] 	Average accuracy score of 30% in both tests, with no significant TA difference between control and sprint tests.	Female, collegiate players. Aged 18.9 ± 1.04 years old.	Sniper-Accuracy Trainer: 5 1X1 ft square cutouts – 1 in each corner of goal (top left, top right, bottom left, bottom right) and 1 in upper middle. TA measured by successful shots made through designated Sniper regions. 5 different shots, 2 attempts per shot. Test 1 control: Participants were given 2 chances to shoot at each of the 5 areas of the Sniper cutouts in randomised order, facing the goal at the 5m line (commonly used for perimeter and penalty shots). Rest period of 35sec given between each shot. After a 2min rest-period participants began test 2. Test 2 sprint: Starting at the 2m line on opposite side of pool, participants sprinted head-down to half-court, and were thrown the ball. Thereafter, they sprinted head-up to 5m line and had 10 attempts at shooting the ball at the target, as for test 1. After each shot,

			they had a 35s period to return to 2-m line at line other end of pool, whereafter the test was repeated.
Panero et al., 2022[178]  	Penalty shot: pre training programme comprising power and precision exercises- 55%, post training programme- 65%.	Females. Aged 22.3 years	A certificated water-polo door (3m inside length, 0.9m inside height, 0.5m depth) was used. Using an individualised algorithm, weighted scores were given to the various throwing areas. Participants made 20 penalty shots at target. The green area (with 0.5m distance from goalposts and 0.3m distance from the crossbar = precision score 5. The yellow area: crossbar and goalposts of the door = precision score 3. Orange area (centre of door) = precision score 1. Red area (beyond the door) = precision score 0.
Freeston et al., 2014[52]	Average accuracy score of 45.3% The GK significantly reduced TA with regard to hit %.	Females in Australian Olympic team. Aged 24.9 years old.	Sniper-Accuracy Trainer: Participants were given 25 throws. The first 15 had no GK, with 5 shots at at each of the 3 areas of the Sniper cutouts (top left, top center and top right), in randomised order. The next 10, taken with GK, with 5 shots each at top left and top right, also in randomised order. A 20-30s rest period given between each 5- throw set, 5min between the no GK and GK set.
Royal et al., 2006[180]	Average accuracy score of 40% and was maintained form at rest, and throughout exertion levels from low to high.	Male junior elite players at Australian Institute of Sport. Aged 17.2 years.	Target with 4 cut out holes (30cm X 30cm) at the bottom left, top left, top right, bottom right. Each participant performed 12 shots. 5 points for clean shot, 3 points for partial contact and 1 point for edge contact.
Van der Wende, 2005[183]  	Average accuracy score of 71.2% (in group without defender or GK).	Males at a national level. Aged 20.8 ± 2.3 years old.	Target was a grid accuracy system; 18 grids of 50cm X 50cm. Each grid assigned a score/5 representing the likelihood of a shot scoring within a game. 1= lowest likelihood, 5= highest likelihood. Participants had 10 shots each.

Botonis et al., 2015[96]	Average accuracy score of 56%.	Males in 1st division. Aged 28 ± 5 years old (range 19-35).	Target (40cm X 60cm) with 30cm hole in the centre. 5 points = ball through hole, 3 points = ball touched hole, 1 point = ball touched edge of hole, 0 = ball didn't touch target.
Baseball			
Keeley et al., 2014[184]	Average accuracy score of 50.8%.	Youth pitchers, aged 11.5 ± 3.1 years old.	Testing took place on an indoor pitching surface and a simulated game situation was used, with participants instructed to pitch on given game scenarios. They pitched through 4 phases of fatigue. In each phase, 3 outs had to be achieved, after which a rest period of average 18 minutes was given. For the 1st phase of no fatigue, an average of 47.53 ± 10.87 pitches were made.
Freeston and Rooney, 2014[36] 	No average accuracy score given.	Males. Aged 21 ± 1.4 years old.	Participants required to throw 40 balls (7.2cm diameter, 156g) at a target which was circular (7cm diameter), 70cm above the ground, correlating with the midpoint of the baseball strike-zone, from a distance of 20m away. Throws were split up into 8 sets of 5 throws each, with a 20sec rest between sets and 3-5 sec rest between throws. Target was surrounded by rubber mat marked with a calibration frame, suspended from a metal frame. Participants performed 10 throws at 70% MTS, 80% MTS, 90% MTS and 100% MTS, respectively. Participants were given feedback on actual speeds for the 70%, 80% and 90% MTS test (measured with radar gun) to adjust accordingly and maintain desired speed. No feedback given for 100% MTS throws. A video camera was positioned 19m away, in-line with the target, to record accuracy scores.
Cricket			
Freeston et al., 2007[55] 	Improved accuracy at 75-85% MTS Average accuracy scores not given.	Females and males. Junior and elite players Aged 15-24 years.	Target – 1 cricket stump surrounded by 5 marked zones progressing outwards from stump, approximately 14cm wide. Participants had 40 throws each (10 at 50% MTS, 10 at 75%, 10 at self-selected speed and 100% perceived max. exertion. Direct stump hit = 0, zone 1 = 1, zone 2 = 2, zone 3 = 3, zone 4 = 4, zone 5 = 5 points. Perfect score = 0, worst score = 50 points.

Freeston and Rooney, 2014[36] 	No average accuracy score given.	Males. Aged 20.4 ± 1.2 years old.	Participants required to throw 20 cricket balls (7.2cm diameter, 156g) at a target which consisted of one cricket stump in the ground (0.71 m × 0.035 m) from a distance of 20m away. Throws were split up into 4 sets of 5 throws each, with a 20sec rest between sets and 3-5 sec rest between throws. Target was surrounded by rubber mat marked with a calibration frame, suspended from a metal frame. Participants performed 10 throws at 80% MTS and 10 throws at 100% MTS. Participants were given feedback on actual speeds for 80% MTS test (measured with radar gun) to adjust accordingly and maintain desired speed. No feedback given for 100% MTS throws. A video camera was positioned 19m away, in-line with the target, to record accuracy scores.
Hydar et al., 2019[181] 	No average accuracy score given. Average improvement of 10.2% post intervention.	Male sub-elite players, aged 20.4 ± 2.03 years old.	A square target of 30.48 X 30.48 cm was marked on a wall, 1.22m from the ground. Participant stood 4.57m away from target and had 3 trials to throw the ball (circumference of 50.8cm) for 30sec as many times as possible. Participants had a familiarisation session of 8 throws prior to the start if the trial. Score was calculated as number of throws within target, divided by total number of balls thrown.
Ahmed et al., 2020[35] 	Amateur: Average accuracy score of 20.7%. Elite: Average accuracy score of 24.7%.	Males. Amateurs, part of local cricket clubs and a university in Cape Town, South Africa (aged 23 ± 4 years old) and elite cricketers (23.9 ± 5.1 years old).	Target board (standard stump set up dimensions). Participants had 5 attempts to throw at more than 80% of MTS, as accurately as possible. Simple scoring system according to area of contact on target, was used. 3 points = green circle. 2 points = inner dark blue rectangle (standard dimensions of wicket set). 1 point = light blue rectangle (missed wicket). 0 points if target missed completely.

Handball			
Papanikolaoy et al., 2021[59]  	Female = 76.6% Male = 74.1%	Adolescent females and males. Aged 15.1 years.	Target (0.8 cm X 0.8cm) square with 8 concentric circles with radius 5-40cm (in increments of 5cm). Participants were 6m from the target and performed 5 throws each. Declining score (8,7 …2, 1) with 8 = 5cm radius circle and 1 = 40cm radius circle.
Zapartidis et al., 2007[168]	Average accuracy ranging between 22-31%.	Females. Aged 20.5 years.	Target (1m X 1m). Circles painted with radius 5-40cm (in increments of 5cm). Participants positioned 7m from target and performed 21 throws.
Van den Tillaar and Ettema, 2003[182]	When only instruction was to hit the target, average accuracy score = 57.1%. When primary instruction was accuracy, with a secondary aim of high velocity, accuracy score = 58.7%.	Male 2nd division Norwegian national players. Aged age 24 years.	The target was 0.5- x 0.5-m^2 in a standard team handball goal. Participants threw from 7m. Each was instructed to throw 7 times as per 5 different randomised instructions, totalling 35 throws. A 1 min rest period was given between throws.

2.5.1 Factors influencing throwing performance

Amongst the different overhead sports, there are a variety of different factors proposed to affect TP. Some are unique to water polo, while others are commonly observed in many sports. Numerous studies have looked at the relationship between different musculoskeletal factors such as GH ER ROM[73,74,164,166], GH rotational strength[53,78,79,167], hip strength[79,90,92], rotational mobility[75], shoulder proprioception[50,95] and different anthropometric variables[63] and TS. Very few studies have actually investigated the effects of these variables on TA. Moreover, a paucity of research exists amongst water polo players, and more specifically adolescent females.

2.5.1.1 Anthropometrics

Recent studies on TP in overhead sports have shown that standing height[58,62,64–67,69,77,81,169–171], body mass[58,61,63–65,71,171,172], body mass index (BMI)[58,60,61,76,172] and age[59,69,72,74] correlated with TS in a number of overhead sports (Table 2.3). Baseball research has shown that incremental increases in both age and height correlated with increased TS[69]. In water polo, age is also positively correlated with increasing TS[58,67] with a ± 48% change from younger to older players as height increases[58]. In addition, for water polo, standing height[58,62,65,66], body mass[58,61,65] (comprising muscle mass) and BMI[58,60,61] were all linked to TS. A recent handball study showed that female adolescent age and age at peak height velocity (APHV) as well as standing and sitting height of male adolescents, all correlates positively with TA[59], but there is limited research on the factors influencing TA in water polo players, particularly female adolescents.

2.5.1.2 Upper quadrant contributions

Shoulder rotational strength is frequently associated with TS[53,67,70,72,78–84,167]. However, the findings in the literature investigating the effect of both GH internal and external rotator strength, are often contradictory. In recent studies on water polo[67,78], cricket[79], handball[80] and tennis[70,72,81,82], GH internal rotator strength was found to be correlated to TS, whilst in another handball population[168], no correlation was observed. Contradictory findings highlight the complexity of predicting TP as different musculoskeletal variables may interact differently in different sports. GH internal rotator strength appears to be a relevant variable to TP, but its association can never be assumed. GH external rotator strength appears to influence TS in tennis and handball players[70,72,80,81,83], but not in all groups within these populations[53,167]. Hand grip strength has been associated with improved TS in handball[85,86], tennis[71,83] as well as water polo[61,62]. However, these findings were mainly observed amongst males, and there is little evidence for female water polo players. The medicine ball throw, a test of upper quadrant power, was shown to predict TS in cricket[79], tennis[71,72,87,88] and handball[63,64], indicating that general shoulder and arm power is important for TS. Upper limb angles of both the elbow and shoulder have been found to influence both TS and TA. A smaller elbow flexion angle correlates with improved TS[178], while a higher shoulder angle correlates with decreased TS, but improved TA[178,185]. Lastly, the contribution of strength from the pectoralis minor muscle has been positively correlated with TS in a water polo population[89,94].

2.5.1.3 Lower quadrant contributions

Hip abduction strength (HAS) is said to be an important component of TS amongst baseball[35,90,133] and cricket. Ahmed (2020)[35] found non-dominant HAS to be significantly correlated to TS. The lateral-to-medial jump, which requires HAS, has been found to correlate positively with TS in both cricket[79] and baseball[92]. No study has investigated the direct contribution of HAS to TP in water polo. Lower limb power, however, assessed with on-land jumping, positively correlates with improved TS in water polo[58]. A 2014 study also demonstrated that maximal dynamometric force via egg-beater kick is significantly correlated with TS[91], highlighting the important contribution of the lower limbs in power generation for TS amongst water polo players. The contribution of stability from the core has also been positively correlated with TS in a water polo population[89,94].

2.5.1.4 Range of motion

GH ER ROM has been found to both correlate[73,74] and not correlate[166] with TS in baseball. A glenohumeral internal rotation deficit (GIRD) has not been shown to predict TS amongst baseball players, but has been linked with injury[186], while in tennis players, a decrease in dominant GH IR ROM has been correlated with a decrease in serve speed[72]. A single study found that a reduced thoracic rotation ROM and decreased dominant hip ER ROM both correlate positively with increased TS amongst cricketers[75]. A baseball study found decreased non-dominant hip TROM to predict TS[187].

2.5.1.5 Proprioception

Proprioception, the ability to sense joint movement in space, has conflicting findings regarding its contribution to TP[21,188]. In water polo, proprioception has shown to predict TS[50], while in baseball it was found to have no correlation to TS[95]. It is proposed that proprioception of the KC in its entirety, could provide better insight, compared to just shoulder proprioception in isolation[95]. Hams et al. (2019)[50] demonstrated that in-water versus on-land testing of proprioception provided varying influence on TP. It was found that in-water proprioception showed a strong positive correlation with TS, amongst a population of females. This is likely due to the effects of the aquatic environment in which the game is played.

2.5.1.6 Fatigue

Fatigue has proved to be negatively correlated with both TS[51,96] and TA[99] in water polo, and TS in baseball[97]. Fitness levels would therefore have an influence on TS and TA[99].

2.5.1.7 Extrinsic factors

There are many extrinsic factors that influence TP. Firstly, the number of water polo playing years (i.e. training age) has been significantly correlated with improved TA[99], as skill acquisition improves. Workload negatively influences TS in water polo[20]. Environmental conditions such as training versus competition has shown to influence TS, where participants are found to throw faster in a competitive situation[98]. In water polo, the presence of a GK correlates with a decrease in both TS and TA[52] and thus coaches should vary these external factors during TP training, for optimal performance on match day. Lastly, the distance from the goal posts influences TS and shooting outside of the 5m is said to be the optimal range for water polo players[56].

There is limited evidence amongst overhead sports on the assessment and effects of TA on TP. This is due to the fact that TA is also strongly influenced by visuomotor skills[189]. Most of the research has investigated factors affecting performance amongst cohorts of baseball players where various anthropometric variables[69,74], lower limb strength[90] and power[92], ROM[73,74] and fatigue[97] have all been found to influence TP. Overall, limited evidence in water polo exists, especially amongst female adolescents.

Table 2.3: Summary of studies assessing throwing performance in overhead sports

Variable affecting TP	Sport	Effect on TP
Anthropometrics		
Gender	Water polo[56,57], cricket[55], tennis[72]	Male gender positively correlates with TS[55–57,72].
Age	Water polo[58], baseball[69,74], handball[59], tennis[70,72]	Age is both positively correlated[69,72,74] and negatively correlated[70] with TS. TS is shown to change ± 48% from younger to older players as height increases[58]. In handball, female adolescent age and male and female APHV positively correlated with TA[59].
Standing and seated height	Water polo[58,62,66–68], handball[59,64,65], baseball[69], tennis[71,76,77,81,169–171]	**Contradictory**: Standing height is both correlated[58,62,64–67,69,71,77,81,169–171] and not correlated[68,76] with TS. In adolescent male handball players, both standing and sitting height positively influenced TA[59].
BMI	Water polo[60,61], tennis[76,172]	BMI is correlated with and affects TS[58,60,61,76,172].
Body mass (muscle mass)	Water polo[58,62,66], handball[63–65], tennis[71,171,172,190]	Body mass (due to increased muscle mass) predicted TS[58,62–66,71,171,172,190].
Arm span, bi-epicondylar humeral breadth, biepicondylar femur breadth, biacromial, biiliocristal breadth, arm and forearm girth	Water polo[61,62,66,140], tennis[71]	Arm span[71], arm and forearm girth[62,66,140], bi-epicondylar humeral breadth[66], biepicondylar femur breadth[61], biacromial, biiliocristal breadth[62] is positively correlated with TS.
Upper Quadrant Strength and Power		
GH Internal Rotator Strength:	Water polo[67,78], handball[80,168], cricket[79], tennis[70,72,81,82,84]	**Contradictory**: GH internal rotator strength is both correlated with TS in water polo[67,78], cricket[79], handball[80] and tennis[70,72,81,82,84] but not correlated with TS amongst another population of handball players[168].

GH External Rotator Strength	Handball[53,167] , tennis[70,72,81,83]	**Contradictory:** GH external rotator strength is both positively correlated[80] and not correlated[53,167] with TS amongst handball players. GH external rotator strength is both positively correlated[72,81] and negatively correlated[70] with TS in tennis. Pugh et al. (2003)[83] found only a moderate correlation between serve speed and shoulder strength in male college tennis players.
Grip Strength	Water polo[61,62], handball[85,86], tennis[71,83]	Stronger handgrip strength correlates positively with TS[61,62,71,85,86].However, Pugh et al. (2003)[83] found only a moderate correlation between serve speed and handgrip strength in male college tennis players.
Wrist flexion and elbow extension torque production	Tennis[70].	Wrist flexion and elbow extension torque production were significantly correlated to TS[70].
Pectoralis Minor strength	Water polo[89]	Pectoralis minor strength is correlated with TS[89].
Medicine Ball Throw	Handball[63,64], cricket[79], tennis[71,72,87,88]	Medicine ball throw predicted TS[63,64,71,72,79,87,88].
Lower Quadrant Strength and Power		
Hip Abduction Strength	Baseball[90], cricket[35]	Dominant hip abduction strength correlates to TS, and maintains ball speed throughout a game[90]. Non-dominant hip abduction strength significantly correlated to TS[35].
Hip and trunk flexion power	Tennis[93]	Hip and trunk flexion power significantly correlated with serve speed[93].
Lower limb power	Water polo[58]	Lower limb power correlates with improved TS[58].
Lateral to medial jump	Cricket[79], baseball[92]	Lateral to medial jump positively correlated with TS[79,92].

Dynamometric force in egg-beater kick	Water polo[91]	Maximal dynamometric force via egg-beater kick (correlating with height, arm span, body mass and BMI) is significantly correlated with TS[91].
Other Variables		
Abdominal strength/stability	Water polo[89,94]	Abdominal strength/stability is positively correlated with TS[89,94].
Pectoralis Major Stiffness	Tennis[177]	A decrease in pectoralis major stiffness correlates positively with TS[177].
Shoulder proprioception	Water polo[50], baseball[95]	**Contradictory**: Proprioception is both correlated to TS in water polo[50], but not correlated to TS in baseball[95].
Range of Motion		
GH ER ROM	Baseball[73,74,164,166]	**Contradictory**: In baseball, GH ER ROM is both correlated[73,74] and not correlated[164,166] with TS.
GH IR ROM	Baseball[164], tennis[72,76]	In u15 male tennis players, decreased GH IR ROM in dominant shoulder = decreased serve speed[72]. GIRD not correlated with TS in baseball[164]. In tennis, dominant shoulder ROM significantly correlated with serve speed[76].
Dominant shoulder flexion ROM	Tennis[70]	In tennis, dominant shoulder flexion ROM is correlated with TS[70].
Upper Limb Angles:	Water polo[178], handball[185]	Smaller elbow flexion angle correlates with greater ball speed[178]. Higher shoulder angle correlates with a decrease in TS but higher TA[178,185] after a 45 day-specific training program[178].
Hip and Thoracic rotation ROM	Cricket[75], tennis[77], baseball[187]	Decreased dominant hip ER ROM and decreased thoracic ROM correlated with increased TS[75]. Increased Non-dominant hip ER ROM positively correlated with serve speed[76,77]. Non-dominant hip TROM is significantly correlated with ball speed[187].
Knee ROM	Tennis[76]	Dominant knee ROM significantly correlated with serve speed[76].

Fatigue	Water polo[51,96,99], baseball[97], tennis[173–176]	Fatigue negatively correlated with TS[51,96,97] and TA[99,173–175]. In tennis scapular muscle fatigue negatively affected serve speed and accuracy[176].
Fitness	Water polo[99]	Fitness level predicts TA[99].
Skill	Tennis[77].	Skill is linked to tennis serve speed[77].
Extrinsic Factors		
Workload	Water polo[20], cricket[55]	Workload predicts TS[20] and TP[55].
Environmental Conditions	Water polo[98]	TS is increased in competition, compared to a training environment[98].
Presence of a GK	Water polo[52]	The presence of a GK correlates with a decrease in TS and TA[52] .
Distance	Water polo[56]	Optimal distance for TS is > 5m[56].
Years of training	Water polo[99]	Greater years of training significantly correlated with TA[99] and TP[55].
Training programmes	Water polo[100], baseball[165]	A 6-week training programme (open/closed kinetic chain/core stability) improved TA compared to control group[165]. An 18 -week heavy-resistance and power training programme improved TS[100].

2.5.2 Throwing performance and shoulder injury

There is a high incidence of shoulder pain amongst overhead athletes[8,191–193], especially water polo players[43,48,110]. A systematic review placed the figure of shoulder pain in these athletes at 24-80%[110], whilst another showed that shoulder injuries were found in 24-51% of players[43]. These findings were mirrored by Jameson et al. (2020)[106] who found that approximately 49% of male adolescent water polo players suffered from shoulder pain in a three-month season. Sallis et al. (2001)[194] showed 11.5 out of a hundred injuries yearly, which was reportedly higher in females.

TP seems to be very dependent on a co-ordinated and strong upper limb quadrant. The high risk and rate of injury to the shoulder in the skeletally vulnerable adolescent[46], appears to represent a failure of this system in response to the load and biomechanics of overhead sports. Musculoskeletal factors in overhead athletes are commonly screened for to evaluate the predictors of TP (Table 2.3) as well as injury risk (Appendix B). The benefits of musculoskeletal testing aids both the prevention of injuries, as well as improving performance. Knowledge of the interpretation thereof should be utilised in conjunction with sport-specific adaptions, found in the different musculoskeletal profile of various sport types[195]. While some factors may be linked to improved performance, it is crucial to establish whether those musculoskeletal factors may also increase the risk of injury. Thus, it is essential to evaluate the musculoskeletal predictors of TP, in the context of musculoskeletal predictors of injury as many of the variables are associated with both. The main ones are an increased GH internal rotator muscle strength[196] and increased GH ER ROM[5], which are correlated with improved performance, but may also increase the risk of shoulder injury[5,196]. While injury itself would affect TP to the greatest degree, if RFs predisposing an athlete to injury can be identified early on, injury can be avoided or prevented[18], thereby boosting performance throughout a season.

It is the interaction between these different RFs that has been shown to result in sports-related injury[197]. However, there are very few high-quality prospective studies with good methodologies and reliable screening tools, when it comes to the identification of RFs[104] and how these RFs can go on to affect TP in the water polo athlete. In the overhead athlete in general, studies have identified the following variables as RFs - dyskinesis of the scapula[28,43,198–200], a decreased GH IR ROM (and/or GIRD)[5,28,199], an increased GH ER ROM (and/or ERG)[5], a decreased TROM[5,201,202], reduced strength of the external rotators[110,159,201,203] (relevant to internal rotator strength), reduced strength of the internal rotators[24] or an imbalance between these two variables[204], weak scapular stabilisers[205–207] and hip muscles[14,192], altered proprioception[43], a decrease in pectoralis minor length (PML)[11,208,209], increased posterior capsular tightness[7,208–210], discrepancies in acromiohumeral distance (AHD)[1,39,211], the female gender[212–215] as well as age[216,217] and height[46]. However there is relatively little evidence with regards to RFs for shoulder injury in water polo, especially in female adolescents.

2.6 The musculoskeletal profile of an overhead athlete

The overhead throwing action is considered to be analogous in many different sports such as throwers, swimmers, baseball pitchers, tennis, volleyball and water polo players[103]. It has been postulated that the musculoskeletal profiles of these athletes are comparable[8]. Although the physical demands between these sports are similar, the biomechanical requirements as well as the nature of the games are very different[137]. It appears that the musculoskeletal profiles may be different as Dutton et al. (2019) found cricketers' musculoskeletal profiles to differ in many respects from baseball pitchers. Many overhead athletes present with scapula dyskinesis[28,29,199], posterior capsule tightness[8] and increased upward scapula rotation (USR)[7]. Discrepancies in AHD[1,39,211] are also observed. An increased dominant GH ER ROM or ERG, and a decreased dominant GH IR ROM, or GIRD, is also present[38,218–220], with some athletes demonstrating muscular imbalances between shoulder rotators, altering the glenohumeral external rotator to internal rotator (GHER:GHIR) strength ratio[8].

2.6.1 The baseball pitcher – The 'thrower's paradox'

As discussed, baseball is the sport that has been used in the literature to model the overhead thrower's shoulder[125,134]. Pertaining to the previously discussed 'thrower's paradox', effective performance requires the athlete to maintain the sensitive balance between optimal mobility and stability[38]. This necessitates a shift in the arc of GH rotational movement, known as TROM, towards maximal GH ER ROM[38,221,222], with a subsequent decrease in GH IR ROM, whilst still maintaining a TROM of 180°[11,38,124,126,166,210,223–225]. The literature has well documented the increase in GH ER ROM (ERG), with a concomitant decrease in GH IR ROM (GIRD) at 90° of abduction in the dominant arm, as compared to the non-dominant arm in baseball players[41,126,193,210,219,220,223,224,226–229]. The ERGs and anatomical GIRDs found in baseball players[210,225,230] are viewed as normal adaptions, unique to overhead athletes, if TROM is maintained bilaterally[231,232] to within a 5° difference[41,218] (Table 2.4).

These adaptions are useful for generating increased force and ball speed during the overhead throw[125,126]. Ball speed is determined by the GH IR speed, which in turn, is determined by the throwing arc length. The more GH ER ROM that exists, the longer the throwing arc[5]. The presence of humeral retroversion in the dominant shoulder of baseball players[202,224,233–237], posterior capsular thickness[8,11,202,230,233] and tightness, have all been considered as contributors to reduced GH IR ROM, as well as the gain in GH ER ROM[236].

Baseball pitchers present with an upwardly rotated scapula at rest[38,230,238] that continues to increase further with increasing degrees of GH elevation, while those with a thickened posterior capsule demonstrate further USR in these positions[230]. The primary force couple of the lower trapezius (LT), upper trapezius (UT) and the serratus anterior (SA) that stabilise the shoulder[31], show lower activation in USR, but stronger activation during the acceleration phase of the baseball throw[239]. In addition, a decreased PML[240], increased LT muscle thickness[241,242] and stronger LT and middle trapezius muscle strength[228] was found in these athletes. Asymmetries in RC muscle strength, represented by the GHER:GHIR strength ratio have been recorded, evidencing lower GH external rotator strength[228,243–245] with concomitant greater GH internal rotator strength[227,245–247]. This stems from a higher dominant GH internal rotator strength, with no balancing increasing strength of the GH external rotators[246,248]. In overhead athletes, the optimal GHER:GHIR strength ratio has been established as 66-75%[15,41,249]. Some studies recorded strength ratios lower than this[244,247,248], with others finding much higher strength ratios of 0.83 – 0.99[204,228]. While these adaptions can improve TP, they may also enhance the risk for overhead athletes in the development of shoulder pain and/or injury[5,201], particularly in baseball players[41,193].

2.6.2 The water polo player

It is assumed that water polo players require adequate GH ROM, especially GH ER ROM for optimal TS as they are required to generate a maximal force, and it is advantageous to be able to do this over a greater rotation range to generate increased ball speed[107]. Akin to baseball players[41,126,193,210,219,220,223–229,250–252], water polo players have been found to present with increased GH ER ROM and a slight decreased GH IR ROM on the dominant side[39,106,108,196]. Studies have also shown water polo players to present with symmetrical TROM values[39,106,108,253,254]. However, while a few studies have evidenced a largely preserved TROM in the dominant shoulder[196,254], others have shown TROM values that fall well below 180°[39,106,108,253,255].

A number of studies have demonstrated an imbalanced dominant GHER:GHIR strength ratio[32,39,106,158,159,196,203,254,256]. Four studies[39,106,254,257] met the recommendation[15,41,249], while ratios in other studies were low, ranging from 50-62%[32,158,159,196,203]. Sioutis et al. (2022)[256] recorded that 64.3% of the participants fell below the recommended normal ratio of 0.65. Shoulder strength ratios for water polo players are generally lower than those found in baseball players[204,228]. In addition, there are differences in absolute strength of the GH rotators. Whilst one study recorded that water polo players evidenced no side-to-side strength asymmetries[39], others have found increased internal[106,196,254] and external rotator[106,254] muscle strength on the dominant side, relative to the contralateral side, mirroring findings for adolescent baseball pitchers[258]. Tully et al. (2022)[196] reported that water polo players exhibit weaker external rotator strength bilaterally, when compared to other overhead athletes. Further, they showed that players presenting with shoulder pain demonstrated increased dominant internal rotator strength scores, compared to external rotator strength scores, altering the GHER:GHIR strength ratio[196]. While having strong internal rotator strength is essential for optimal TP[67,70,72,78–82,84], it might predispose athletes to an increased injury risk[196], highlighting the need to strengthen these muscles symmetrically, ensuring a healthy GHER:GHIR strength ratio. These wide differences seen in GH muscle strength ratios and absolute strength of the rotators could be due to varying participant demographics. This stresses the need for extrapolating studies across gender, age groups and level of competition. Also, given that most of the studies were conducted with male water polo players, this identifies a need for studies on females, to establish normative strength data for this population.

A coordinated pattern of movement is involved in the throwing action, wherein the scapula is upwardly rotated and posteriorly tilted[11,27]. A water polo player has been found to present with a downwardly rotated scapula at rest[106,196], but increasing USR on the dominant, compared to the non-dominant side, especially at 90 degrees of GH abduction[106]. The pectoralis minor muscle is significantly shorter on the dominant side[106,196], while a tight posterior capsule has been observed[40,203]. Furthermore, altered proprioception[43] amongst these athletes has been recorded.

Good scapular strength is important for scapular and GH performance, and may influence TP, as it provides a stable base for RC function. The trapezius, SA and pectoralis minor muscles all help contribute to this process[29]. However, there are not many studies investigating this muscle strength in water polo players, and for the most part this was evaluated with regards to injury prevention. Scapular muscle strength in the form of symmetrical SA and UT scores were observed in one study[106], while Tully et al. (2022)[196] found asymmetrical scores with increased SA and UT strength on the dominant side. In addition, asymmetrical[106,196] and weakened[158] LT muscles have been identified, while weak SA scores have been recorded in the scapulae of injured players[106]. This further highlights the contradictory findings and lack of normative data on the musculoskeletal profile of a water polo player.

2.6.3 Other overhead athletes

Swimmers present differently to the typical baseball musculoskeletal profile as they appear to have more laxity of their GHJ capsules which can be worsened by repeated overhead motions and increased demand while swimming[218,259,260]. They present with a more symmetrical profile by demonstrating bilateral decreases in PML[19,24,212], which is reflective of the symmetrical nature of their sport. The typical ERG is observed amongst this population[261], but contradictory results regarding GH IR ROM exist, where some swimmers have been found to display a GIRD[262], while others present with normal GH IR ROM compared to a normal age-related population not involved in competitive swimming[261]. Scapular muscle strength in swimmers differs to water polo players as they have stronger SA and LT strength, but weaker UT strength on the dominant side[263]. Finally, they present with a marked decrease in the GHER:GHIR strength ratio compared to other sports[264] and non-swimmers[265].

Cricketers have shoulders which are markedly different to the typical throwers shoulder described in baseball. They do not exhibit an ERG[102,230], which is typically observed along with GIRD in the baseball pitcher[41,126,193,210,219,220,223–229,250–252], or a reduced AHD measurement seen in other overhead athletes[266]. Importantly, they do not demonstrate the osseous adaption of humeral retroversion[267]. They do however, exhibit a substantial GIRD and resultant loss in TROM[102]. They present with a consistently downwardly rotated scapula from rest up until 90° of GH elevation as well as normal PMLs as seen in healthy male non-athletes[268]. Cricketers have normal GHER:GHIR strength ratio[156] but reduced absolute internal and external rotator strength[102] compared to baseballers[228]. This global weakness could lead to a decreased TS[125,126] as well as alterations in the overhead throwing motion, increasing the risk of injury if the KC does not function correctly[102]. They also display a lack of GM muscle strength and a bilateral decrement in hip ER ROM[75] and TROM. Lastly, compared to baseballers, they present with relatively normal UT strength, greater LT strength and poor SA strength[102].

Tennis players seem to follow the typical 'thrower's paradox' of a baseball pitcher[27,38] as they present with many of the same musculoskeletal variables. This includes an ERG, concomitant GIRD[195,219,269,270], increased USR on the dominant side[7], a decreased dominant PML[7] and a loss of the AHD measurement[271]. While baseballers largely preserve TROM bilaterally[41,186], tennis players display a significantly lower TROM[272,273]. This TROM deficit was found to further decrease with increased years of play in elite tennis players[270,274]. Females are found to display greater shoulder hypermobility[275], while reductions in hip ROM have also been observed[276]. Tennis players display greater GH internal rotator strength of the dominant arm, but no increase in GH external rotator strength[219,273], exhibiting an imbalance in the GHER:GHIR strength ratio[269,272], commonly seen in other overhead athletes[106,159,203,257,258,264]. Furthermore, they possess stronger dominant SA and UT muscles, compared to the non-dominant side[7], with no bilateral difference in LT strength[7], in contrast to baseball players[228].

Akin to other overhead throwers, handball players display significantly increased GH ER ROM, with corresponding decreased GH IR ROM in the dominant shoulder compared to the non-dominant shoulder[215,277,278], leading to a decreased TROM[215]. It has also been proposed that the decreased TROM is caused by posterior capsule and muscular tightness in the GHJ[103,230,279]. Handball players have shown a decreased AHD in the dominant shoulder in 60° of GH abduction and the non-dominant shoulder at 0° and 60° of GH abduction[280]. Absolute dominant shoulder posterior capsule thickness is noted in handball players[277] , baseball players[230] and water polo players[40,203] and when compared to the non-dominant shoulder[277]. Handball players exhibit an increase in dominant shoulder internal rotator[281] and abduction strength, which is juxtaposed with a decrease in external rotator strength[201,215,278,282]. The dominant GHER:GHIR strength ratio is significantly lower than the general population, and lower for the dominant side compared to the contralateral side[281,282].

Table 2.4: The musculoskeletal profile of an overhead athlete

	Scapula Positioning	Flexibility	ROM	Muscle Strength	Other
Baseball pitchers	- Upwardly rotated scapula at rest[38,230,238] - Increased dominant side USR at 60°, 90° and 120° of GH abduction[27,38,230,238] - Increased posterior capsule thickness = Increased USR at 60°, 90° and 120° of GH abduction[230]	- Decreased dominant side PML[240] - Posterior shoulder tightness[8,11,202,230,233,236] - Increased posterior capsule tightness and thickness on dominant side compared to non-dominant shoulder = GIRD[230]	- Increased dominant side GH ER ROM (ERG) and decreased GH IR ROM (GIRD) compared to non-dominant side[41,126,193,210,219,220,223–229,250–252] - Preserved TROM[11,38,124,126,166,210,223–225] - Increased retroversion of humerus[202,221,222,224,233–237] - Increased posterior capsule thickness on dominant side = increased ER ROM and decreased IR ROM on dominant side[230]	- Increased dominant side GH internal rotator strength[227,245–247] and decreased dominant side GH external rotator strength[228,243–245] - Dominant side GHER:GHIR strength ratio imbalance - **contradictory**: some found less than recommendation[244,247,248] and some found greater than recommendation[204,228] - Increased LT muscle thickness[241,242] and increased LT and MT strength on dominant side[228] - College baseball players = 12% decrease in supraspinatus strength in dominant arm[283]	- AHD: Contradictory: Increase in dominant side AHD[284] but no difference found in AHD between dominant and non-dominant sides[230]
Water polo players	- Downward scapula rotation at rest[106,196] - Increased USR on dominant side compared to non-dominant side and to uninjured players at 90°[106]	- Decreased dominant side PML[106,196] - Posterior capsule tightness[40,203], but **contradicted** by Turgut et al. (2017)[285]	- Increased GH ER ROM (ERG) and decreased GH IR ROM (GIRD) on dominant side [39,40,106,108,196,286] - GH TROM **contradictory**: Some found TROM on dominant side to be largely preserved[196,254] while others found GH TROM on dominant side to be well below 180°[39,106,108,253,255] - Symmetrical TROM scores[39,106,108,253,254]	- Increase in dominant side GH internal rotator strength[106,196,254] and increase in GH internal and GH external rotator strength relative to non-dominant side[106,254] - **Contradictory:** Equal GH internal rotator and GH external rotator strength bilaterally[39] - Decreased absolute external rotator strength on dominant and non-dominant sides compared to other overhead athletes[196] - Increased dominant side internal rotator muscle strength in injured players[196]	- Negative correlation between trunk extension and shoulder GH ER and GH IR rotation, especially in females[256]

				- Decreased GHER:GHIR strength ratio on dominant side[32,39,106,158,159,196,203,254,256,257] - Decreased GHER:GHIR ratio below recommendation[32,158,159,196,203] - GHER:GHIR ratio above recommendation[39,106,257] - Symmetrical UT and SA scores[106] but **contradicted** by Tully (2021)[196] who found increased UT and SA strength on dominant side relative to non-dominant side. - Decreased LT on dominant side compared to non-dominant side[158] - Asymmetrical LT scores[106,196] - Decreased dominant SA strength in injured players[106]	
Swimmers	- Scapula dyskinesis[287]	- Decreased bilateral PML[19,24,212] - Increased posterior shoulder tightness, represented by less horizontal adduction, compared to non-overhead athletes[262,288] - Lax joint capsules, worsened by repeated overhead motions[218,259,260]	- Increased GH ER ROM (± 15°) but normal GH IR ROM compared to age-related population not involved in competitive swimming[261] but contradicted by Torres and Gomes (2009)[262] who found GIRD.	- Imbalance in shoulder muscle strength groups[264] with decreased GHER:GHIR strength ratio (with GH internal rotators being stronger) compared to non-swimmers[265] - Decreased absolute GH internal rotator, external rotator and shoulder flexor muscle strength in swimmers with scapula dyskinesis than those without scapula dyskinesis[289] - Increased SA and LT strength but decreased UT strength on dominant side[263]	- Decrease in AHD[290]

Cricketers	- Downwardly rotated scapula from rest to 90° degrees elevation[102]	- Relatively normal PML[102] - Tight posterior capsule[102]	- No ERG[102] - Decreased GH TROM = GIRD on dominant side[102] - No humeral retroversion[267] - Faster bowlers = decreased hip ER ROM[75]	- Global decreased shoulder muscle strength compared to normative data[102] - Increased dominant internal and external rotator strength compared to non-dominant side in uninjured group[102] - Decreased absolute strength of internal and external rotators[102] - Normal GHER:GHIR strength ratio[156] - Decreased SA strength[102] - Increased LT strength[102] - Normal UT strength[102]	- No discrepancies in AHD[102]
Tennis players	- Increased degree of dominant USR[7]	- Decreased PML on dominant side[7] - Females = increased hypermobility[195,275]	- Decreased GH IR ROM (GIRD) and increased GH ER ROM (ERG) and decreased TROM on dominant side[195,262,269,270,272,273]	- Increased dominant side GH internal rotator strength but no increase in dominant side GH external rotator strength[219,269,273] - GHER:GHIR strength ratio imbalance on dominant side[269,272] - Increased SA and UT strength on dominant side but no bilateral LT strength difference[7]	- Decreased AHD with shoulder raised from 0° and 60° abduction on dominant side. Increased AHD in presence of scapula dyskinesis[271] - Decreased hip flexion, extension, abduction ROM in both lower limbs for both sexes. In males, decreased hip IR ROM[276]

Handball players	- Scapular dyskinesis[201]	- Increased posterior capsule thickness on dominant side relative to non-dominant side[277]	- Increased GH ER ROM and decreased GH IR ROM and GH TROM on dominant side[215,277,278] - GIRD[291] - Dominant side GH ROM = other experienced athletes[280] - Increased GH ER and abduction with nominal flexion and extension of shoulder[135]	- Increased GH internal rotator strength and decreased GH external rotator strength and increased abduction strength in dominant shoulder[201,215,278,281,282] - Decreased absolute GH external and GH internal rotator and abduction strength bilaterally[280] - Decreased GHER:GHIR strength ratio on dominant side relative to non-dominant side and general population[281,282] - Decreased GHER:GHIR strength ratio in non-dominant arm compared to controls[280] - Increased constricted thickness of LT in dominant arm = Increased GH internal rotator strength[292]	- Decreased AHD on dominant side in 60° abduction and on non-dominant side in 0° and 60° abduction[280]

**The above reported sports are not all existing overhead sports, however, they do have the largest amount of research investigating these parameters.*

2.7 Conclusion

The unique sport of water polo requires swimming, passing and shooting of a ball in an aquatic environment, without a stable base of support, placing an increased load on the GHJ[111]. Factors identified to influence TP amongst water polo players include anthropometric variables (age, gender, standing height, BMI, body mass), upper limb strength (GH internal rotator strength, pectoralis minor strength, grip strength), lower limb power, core strength, shoulder proprioception, fatigue and other extrinsic factors (workload, environment, presence of a GK, distance, training age). However, there is limited evidence regarding the predictors of TP in water polo, as they appear to differ amongst the overhead sports, especially in female adolescent water polo players. Much of the evidence is contradictory, which limits extrapolation of findings between sports, genders, ages and competitive level.

The musculoskeletal profile of an overhead athlete also differs greatly amongst the various sports. The water polo player profile is described in terms of the following variables – a downwardly rotated scapula at rest[106], an ERG and slight concomitant GIRD in the throwing arm[39,40,286], altered proprioception and there is contradictory evidence regarding asymmetrical GH rotator strength. There is limited literature on the musculoskeletal profile of a water polo player and even less known about adolescent females.

There is limited evidence for the musculoskeletal profile and predictors of TP of female overhead athletes and water polo is no different. The necessity of more robust, high-quality studies amongst adolescent water polo players, specifically females, is highly recommended and further research is needed to examine the factors affecting TP amongst this population.

CHAPTER 3: 'THE MUSCULOSKELETAL PROFILE OF FEMALE ADOLESCENT ELITE WATER POLO PLAYERS AND THE FACTORS AFFECTING THROWING PERFORMANCE.'

Abstract

Background

The musculoskeletal profiles of water polo players and other overhead athletes have been shown to relate to injury and throwing performance (TP). There have been no robust studies conducted on the musculoskeletal profiles and the variables affecting TP in female adolescent elite water polo players.

Methods

A cross-sectional quantitative cohort design was conducted amongst eighty-three female adolescent elite water polo players, ranging 14-19 years old. All participants filled out the KJOC questionnaire, followed by a battery of screening tests, aimed to identify possible musculoskeletal factors associated with TP. Pain provocation tests, GH ROM, USR, GH rotator strength, scapular muscle strength, medicine ball throws and PML measurements, were all included. Participants also performed throwing speed (TS) and throwing accuracy (TA) tests. All the data collected was grouped together and analysed using SPSS 28.0. The condition for statistical significance was set as $p < 0.05$. Multi-collinearity was tested for among variables to find out inter-variable correlations. Finally, a multiple regression analysis (MRA) was performed.

Results

The mean KJOC score was 82.55 ± 14.96. The musculoskeletal profile of the group included increased dominant GH ER ROM while GH IR ROM and TROM was largely preserved, a downwardly rotated scapula at rest, a GHER:GHIR strength ratio of 0.8, strong scapula stabilisers but asymmetrical LT scores, and a shorter dominant PML. Age group was the only variable significantly correlated with TS ($p < 0.001$), while dominant GH IR ROM was the only significant variable inversely correlated with TA ($p = 0.02$).

Conclusion

While there are multiple musculoskeletal factors that may influence TP in this group of female adolescent elite water polo players, age group and dominant GH IR ROM were the only factors to be significantly correlated to TS and TA, respectively, after the MRA.

3.1 Introduction

Success in any overhead sport depends on athletes having competent throwing abilities[35]. Similarly, when it comes to water polo, shooting for goal is an essential skill[293], but also a complex skill, comprising both TS and TA parameters[294]. Thus, research has aimed to determine the factors that positively influence TP. A successful shot requires high speed and accuracy. The former is important as the faster the ball is travelling, the less time the GK and defenders have to block the shot. TA ensures that the ball is aimed at the goals while avoiding interception by defenders and the GK[52].

Amongst throwing sports such as cricket[55] and handball[182,295], a speed-accuracy trade-off exists. The speed-accuracy trade-off refers to the maximal TS, which allows for optimal accuracy. For male handball players, this occurs at 92-93% of maximal throwing speed (MTS)[182,295]. However, lower values of 75-80% of MTS have been recorded amongst cricketers of both genders, when asked to prioritise accuracy, over speed[55]. A water polo study amongst elite females has determined the speed-accuracy trade-off to be 90.1%[52]. As such, it is important that both speed and accuracy be assessed to provide insight into TP[52].

Obtaining an optimal TS relies on many different anthropometric and musculoskeletal variables, in addition to visuomotor skill[98,296]. Skill comprises a series of movements, requiring input from both the motor and vestibular system[297]. In water polo, TS ranges between 25.9 and 49.7 mph[20,51,52,56,58,60–62,66–68,89,91,94,96,98,140,178,180,183,298]. Similar values are recorded amongst handball players[53,63,64,80,167,168], while much higher speeds are observed in baseball and cricket, where speeds reach up to 80 mph[74,90,299] and 75.7 mph[35], respectively.

Factors that influence TP (in the form of both TS and TA) in overhead athletes, include anthropometric variables such gender[55–57], age[58,59], weight[58,61–66] and height[58,62,64–67,69]. GH internal[67,78–81] and external[70,72,80,81,83] rotator strength and grip strength[61,62,71,83,85,86] were found to predict TS. Upper body power, using the medicine ball throw, amongst handball and cricket players can predict TS[63,64,79]. Lower limb power[58] and HAS[35,90] have also been identified as predictors of TS in water polo, cricket and baseball. Abdominal stability[89,94] and pectoralis minor strength[89] have been positively correlated with TS in water polo players. It is unclear from the literature if shoulder proprioception consistently influences TS[50,95].

These intrinsic factors must be seen in the context of external factors such as workload[20,55], environmental conditions[98], the presence of a GK[52], distance[56] and training age[300], all of which have been found to influence TS and TA in water polo specifically. Moreover, the factors affecting TP differ greatly amongst the different overhead sports, as athletes present with contrasting musculoskeletal profiles[102,219,301]. However, there exists a paucity of research investigating the unique musculoskeletal profile of a female adolescent water polo player and whether these attributes are comparable to other overhead athletes. There is also limited evidence exploring factors affecting TP in waterpolo, especially the component of TA, again particularly in female adolescents. The aim of this study was to describe the musculoskeletal profile of female adolescent water polo players, and to investigate which of these musculoskeletal variables are associated with TP (TS and TA). In addition, this study aimed to investigated side-to-side asymmetry of the musculoskeletal variables and the extent to which these variables changed with increasing age.

3.2 Methodology

3.2.1 Research design and participants

This study utilised a quantitative cohort design that was conducted amongst female adolescent elite water polo players. All female provincial water polo players selected to play in the under-14 (U14), under-15 (U15), under-16 (U16) or under-19 (U19) age groups were invited to participate in this study. A saturation sample, where all players available on day of testing, was conducted. Rigorous statistical analysis was used to counter the small sample size and ensure valid and reliable results. The study had institutional ethics approval (576/2021) (Appendix C and D), and participants and parents provided informed assent and consent (Appendix E, F and G).

3.2.2 Inclusion and exclusion criteria

Participants were invited to participate in the study if they were a female water polo player selected to represent Western Province (WP) A and B in the U14, U15, U16 and U19 teams. Participants were excluded from the study if they had an active injury that prevented participation in any of the screening or pool-based performance tests, or were unavailable for the testing days provided.

3.3 Study procedure

The pre-season screening and performance testing was conducted at an indoor testing venue and indoor swimming pool. All the tests included in the screening battery demonstrate high inter and intra-rater reliability with a well described methodology. All the investigators were qualified clinicians and for the most part measured the same parameter on all participants to improve reliability of the data. Anthropometric and demographic data in the form of age group, body mass (kg), standing height (cm) and sitting height (cm) was recorded[12]. BMI was then calculated.

To calculate standing height, participants stood barefoot, heels flat on the floor and against a wall. To calculate sitting height, participants were seated on a chair, 50cm above the ground. Both standing and sitting height were measured in centimetres (cm). Peak height velocity (PHV), defined as the period where an adolescent experiences their fastest upward growth spurt[16], was calculated. Years from peak height velocity (i.e. maturity offset value) was predicted following the protocol described by Mirwald et al. (2002)[12]. The body mass, standing height and seated height from the anthropometric data was used. The following equation was used:

$$Maturity\ offset = -16.364 + 0.0002309\ (Leg\ length\ \&\ Sitting\ Height\ interaction) + 0.006277\ (Age\ \&\ Sitting\ Height\ Interaction) + 0.179\ (Leg\ by\ Height\ ratio) + 0.000942\ (Age\ \&\ Weight\ Interaction)$$

The Coefficient of Determination (R^2) was found to be 0.91 and 0.5 for Standard Error of Estimate. The maturity offset can also be estimated within an error of 1 year 95% of the time[12]. The APHV were determined by the following equation:

$$Age\ of\ PHV = Chronological\ age - maturity\ ofset$$

Participants completed the KJOC questionnaire (Appendix H), which has been proven to be both a valid (r =0.84-0.86) and reliable (ICC = 0.88) tool in the assessment of shoulder and elbow functionality amongst overhead athletes[302]. The KJOC questionnaire contains three sections totalling 19 questions, aimed to assess functionality, performance and self-reported shoulder or elbow symptoms as well as performance-related interpersonal relationships. Questions are measured using a visual analogue scale (VAS) scale, where the extreme left demonstrates the lowest possible functionality or performance levels with the greatest severity of pain, while the extreme right demonstrates the highest possible functionality or performance levels, with the lowest possible severity of pain.

3.3.1 Covid compliance

Throughout the duration of the study, COVID-19 protocols were adhered to. Temperature checks with an infrared thermometer were done on arrival. Moreover, a quick symptom survey (Appendix I) was conducted whereby participants reported if they were experiencing any worrying symptoms such as a cough, sore throat, headache, loss of taste or smell as well as generalised body weakness or fatigue.

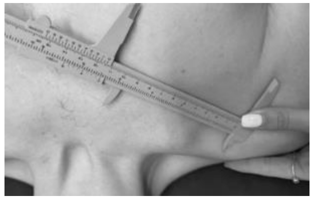
There were sanitiser stations set up in and around the testing venue and participants as well as the testers were required to sanitise in between testing participants.

3.4 Musculoskeletal screening

All participants underwent an anthropometric assessment as well as battery of screening tests prior to the start of the 2021/22 water polo season (Appendix J). The tests are summarised in Table 3.1 and are described further below.

Table 3.1: Preseason musculoskeletal screening

Test Type	Test Protocol	Example and Instruments	Test Type	Test Protocol	Example and Instruments
Hawkins /Kennedy: (Hegedus et al. (2007)[303] Pain (Yes/No)	Participant seated, examiner stabilises participant's scapula before placing participant's arm over their own. Examiner then performs passive GH IR in 90° GHJ flexion. Participant indicates if they are feeling any pain with a yes/no answer.		**GH internal and external rotator strength (Roy et al., 2009)[304]**	Participant seated with arm at 90° GHJ abduction, 90° GH ER and 90° elbow flexion. Participants' forearm stabilised by examiner and instructed to resist manual force, measured with a hand held dynamometer (HHD), by bringing arm back for ER and bringing wrist down for IR. Maintain the testing position for 2-3 secs.	
Jobe's/ Empty Can: (Cools et al., 2008)[305] Pain (Yes/No)	Participant standing with both arms at 90° GHJ flexion and full GH IR (thumbs downwards). Examiner applies downward force resisting more GHJ flexion. Participant maintains position for 2-3 sec.		**Serratus anterior strength (Cools et al., 2010)[7]**	Participant supine with arm at 90° flexion and full elbow extension. A downward force is applied by examiner as participant is instructed to lift scapula off bed and move palm to ceiling. Measured with HHD.	
Full Can: (Cools et al., 2008)[305] Pain (Yes/No)	As above for Empty Can but participant in full GH ER (thumbs upwards).		**Upper trapezius strength (Cools et al., 2010)[7]**	Participant seated with arm by side. Participant is then instructed to perform scapula elevation to counter-act force applied by examiner.	
GH IR and ER ROM: (Kolber and Hanney, 2012)[306]	Participant supine with 90° GHJ abduction and 90° elbow flexion. Examiner stabilises forearm in neutral and directs participant to move arm into thumb-up position for ER and then into thumb-down position for IR ROM measurement, with goniometer.		**Lower trapezius strength (Cools et al., 2010)[7]**	Participant prone, with GHJ abducted to 145° and in full ER (thumbs upwards). Participant required to lift arm upwards towards ceiling, to counter-act force applied by examiner. Measured with HHD.	

Upward scapula rotation: (Watson et al., 2005)[307]	Participant standing while examiner measures USR (with an inclinometer) at 0°, 45°, 90° and 135° of GH abduction with inclinometer against participant's scapula spine.		**Gluteus medius strength (Widler et al., 2009)**[308]	Participant in side-lying, with arms folded over chest. Bottom hip and knee flexed to 30°, while top leg is tested in full knee extension with 10° of abduction. Participant required to perform maximal hip abduction against a downward force applied by examiner. Measured with HHD.	
Pectoralis minor length (Cools et al., 2010)[7]	Participant supine with arms neutral at sides. Distance between coracoid process and 4th rib is marked with a pencil and then measured with a calliper.		**Medicine ball throws (Harris et al., 2011)**[309]	Participant sitting and required to throw a medicine ball straight ahead of them, as far as possible, using a basketball chest pass. Participants have three attempts, and the maximum distance the ball travels will be recorded[309].	

3.4.1 Pain provocation tests

The Hawkins/Kennedy test and the Empty Can (Jobe's) test evaluated potential subacromial impingement. The former has a sensitivity of 79% and specificity of 59%[305]. The participant stated whether they were experiencing any pain with a simple yes/no answer and weakness was also noted. Jobe's test, along with the Full Can test, also evaluates the integrity of the supraspinatus tendon. There is limited evidence for sensitivity, specificity and accuracy of these tests[303] and therefore, results should be interpreted in conjunction with other impingement tests.

3.4.2 Range of motion measurements

GH IR and ER ROM was measured with a goniometer. Excellent validity (ICC values ≥ 0.85) and reliability (ICC = 0.94 – 0.98) has been found for goniometer use and the measurement of GH ROM[306]. The protocol as described by Kolber and Hanney (2012)[306] was followed. The instantaneous axis of rotation was the olecranon of the elbow. The fixed goniometer arm was placed perpendicular to the ground, while the moving arm was placed parallel to the ulna shaft. Participants had both their left and right GH ROM measured twice and the average was recorded.

USR was measured following the protocol set out by Watson et al. (2005)[307]. This method of assessment has been found to display excellent intra-rater reliability (ICC = 0.89 – 0.96) and good-excellent validity[307,310]. A velcro strap was used to stabilise an inclinometer at 0°, perpendicularly to the distal end of the humeral shaft and the floor. The position of the participant's humerus was in a resting position in relation to the floor. Participants were then told to abduct their arms to 45°, 90°, 135° and 180°. USR was recorded at each of these positions of abduction using another inclinometer that was manually operated and positioned along the spine of the scapula of each participant. This was measured twice and an average of the two was recorded.

3.4.3 Isometric muscle strength tests

A hand-held dynamometer (HHD), a valid tool to measure isometric shoulder strength[304] and isometric hip strength[308], was used to assess the isometric muscle strength of the GH internal and external rotators, GM as well as the scapular stabilisers (SA, UT and LT). Good intra-rater reliability was found for GH internal rotator strength (ICC = 0.64 – 0.96), while excellent intra-rater reliability was found for GH external rotator strength (ICC = 0.78 – 0.98)[311]. Moreover, good intra-rater reliability (ICC = 0.90) and construct validity has been established for this method of measuring isometric GM muscle strength[308]. Lastly, a HHD was found to have excellent intra-rater reliability (ICC = 0.79 – 0.96) when measuring shoulder movements[7,312]. To familiarise the participants with the process of muscle strength testing, they performed three isometric repetitions at 70% maximum voluntary contraction for each movement.

3.4.4 Flexibility test

PML was recorded following the protocol by Cools et al. (2010)[7], an adapted version of the protocol set out by Borstad (2008)[313], which demonstrated good validity. This protocol has poor to moderate inter-rater reliability but good-to-excellent intra-rater reliability[122]. Two anatomical landmarks – the coracoid process inferomedial angle and the lateral location of the sternocostal joint of the inferior aspect of the fourth rib – were marked off. The distance between these two points were measured using a caliper (cm).

3.4.5 Upper body power test

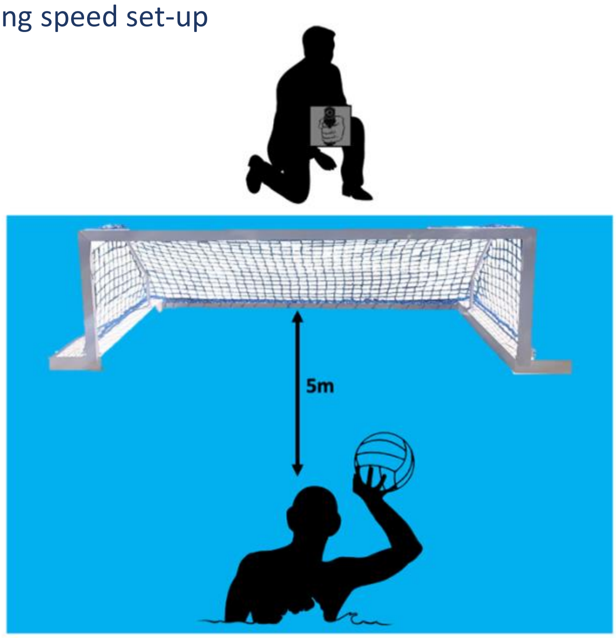
This test was performed with the participant sitting on the floor with their back against the wall and legs extended in front of them[309]. Participants were required to throw a medicine ball straight ahead of them, as far as possible, using a basketball chest pass[314], which assessed shoulder and trunk power. Participants had three attempts, and the maximal distance the ball travelled was recorded. This has been proven to be valid and reliable[309].

3.5 Throwing performance testing

3.5.1 Throwing speed

A radar gun (Stalker Pro, Applied Concepts, Inc. Texas, USA) was used to record TS in miles per hour (mph) for this component of TP testing. Participants' shoulders were warm from the prior strength testing. Participants were instructed to get into the swimming pool and perform 8-12 widths as warm-up. They were then told to tread water 5m away from the goalposts. Two throws using a standard-sized water polo ball (with a mass of 450g and a circumference of 70cm) were then performed using the dominant arm at MTS, using their usual throwing technique. It was stressed that the maximum speed was the aim of these two throws. The person operating the radar gun crouched down behind the goals and aimed it at the ball. The trigger was pulled as the athlete was instructed to shoot, and the trigger was released as the ball hit the cage[52,315] (Figure 3.1).

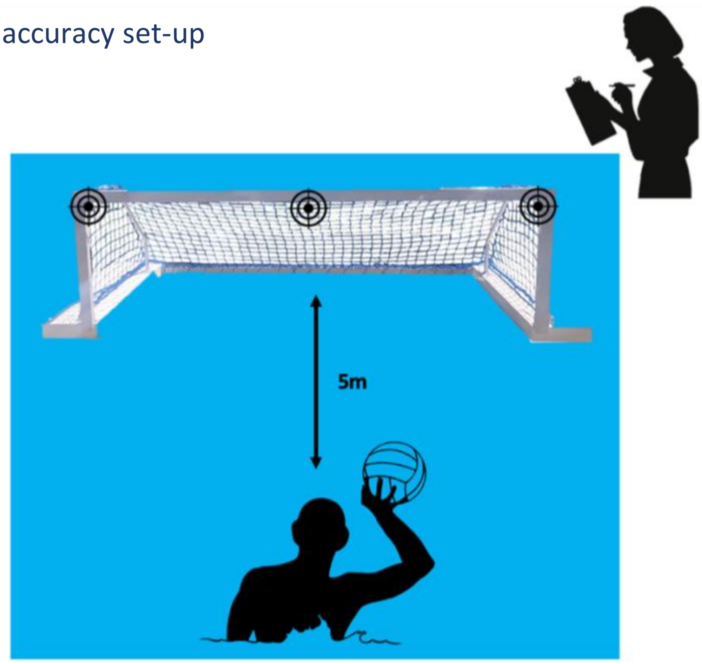
Figure 3.1: Throwing speed set-up



3.5.2 Throwing accuracy

TA was assessed after TS. Here, three targets (15cm X 20cm) were set up against the goal posts. They were placed in the top left corner, top centre, and top right corner, respectively. Participants were instructed to tread water 5m away from the water polo goal posts and each participant had eight attempts to hit any of the three targets (Figure 3.2). Accuracy scores were only awarded if there was a direct hit on any of the three targets. A standard-sized water polo ball was used and they were instructed to throw with more than 80% of their MTS, with maximal accuracy. Accuracy was emphasised as the main aim of these throws. A simple scoring system was used whereby athletes were awarded one point for every successful attempt and received a score out of eight.

Figure 3.2: Throwing accuracy set-up



3.6 Data analysis

All data was captured into an Excel spreadsheet, where mean (average) scores and standard deviations were calculated. GIRD was calculated by taking the non-dominant side glenohumeral internal rotation values and subtracting the dominant side glenohumeral internal rotation values. ERG was calculated by taking the dominant glenohumeral external rotation values and subtracting the non-dominant glenohumeral external rotation values. Finally, the TROM values were calculated by adding the GH IR ROM value to the GH ER ROM value, for both the dominant and non-dominant sides.

3.6.1 Statistical analysis

All the collected data was grouped together and analysed using SPSS 28.0 (IBM, Armonk, New York, USA). The condition for statistical significance was set as $p < 0.05$. In order to do a multiple regression analysis (MRA), four conditions had to be met. These conditions are normality, linearity, lack of multi-collinearity, and homoscedacity. For the statistical analysis, TS and TA were considered dependent variables, while the rest were the independent variables. Firstly, the Shapiro-Wilk test was performed to assess normality of data, and descriptive statistics were calculated for all variables. As TS and TA were found to be not normally distributed ($p < 0.05$), bivariate Spearman's correlation was then used to test for linearity. The independent variables having statistically significant correlations with the correlation coefficient of > 0.3 were initially selected for building the model[316]. Multi-collinearity was tested for among variables to find out inter-variable correlations. Furthermore, multicollinear diagnostic features such as multicollinearity tolerance and variation inflation factor (VIF) were used to guide the final model. A cut-off of 5.0 was set for VIF to make sure that multicollinearity amongst the dependent variables did not adversely affect the model. Homoscedasticity of the model was determined by fitting a Loess curve to the scatter plot of standardised residuals and standardised predicted values. Lack of slope in the Loess curve guaranteed the homoscedasticity of the model. To build the final model, eight independent variables with significant correlation with the dependent variable were chosen in a descending order of their correlation coefficient. If the presence of any independent variable violated the regression diagnostics explained above, the variables were taken out of the model in a step-wise manner. Only once all the regression diagnostics were satisfied by the remaining variables, the outcomes of the multi-linear regression model for TS and TA were tabulated.

3.7 Results

3.7.1 Participants

Eighty-three female water polo players between the ages of 14 and 19 years old, participated in this study. There were twenty-one U14s, twenty-four U15s, fifteen U16s and twenty-three U19s. The group's age range was 14-19 years old. The average PHV was 10.67 ± 0.53. This indicates that 100% of the study population were above their PHV. The majority (90.4%) of our participants were right-handed. The descriptive characteristics of the group can be found in Table 3.2.

Table 3.2: Characteristics of female water polo participants

	Total (n = 83)	U14 (n = 21)	U15 (n = 24)	U16 (n = 15)	U19 (n = 23)
Height (cm)	169.23 ± 6.1	167.45 ± 6.6	168.63 ± 5.76	169.53 ± 6.04	171.28 ± 5.74
Weight (kg)	65 ± 7.5	63.55 ± 6.93	66.56 ± 8.87	64.7 ± 6.32	64.87 ± 7.32
BMI (kg/m^2)	22.68 ± 0.52	22.73 ± 2.77	23.37 ± 2.57	22.47 ± 1.27	22.15 ± 2.72
Peak Height Velocity (PHV)	10.67 ± 0.53	10.17 ± 0.34	10.41 ± 0.4	10.7 ± 0.4	11.4 ± 0.44

3.7.2 Kerlan-Jobe Orthopaedic Clinic (KJOC) scores and pain provocation tests

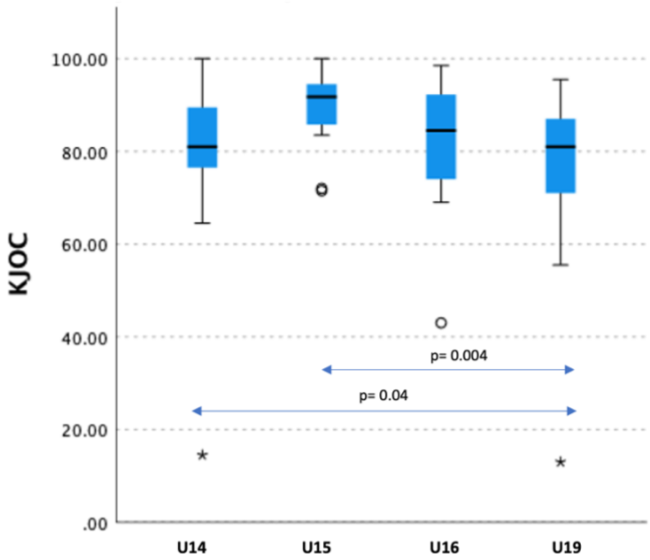
The mean KJOC score was 82.5 ± 15 and it was not correlated with either TS or TA. Twenty-two (26.5%) of the eighty-three participants tested positive for at least one of the impingement tests (Hawkins/Kennedy, Empty Can or Full Can) (Table 3.3). Among the participants with at least one positive impingement test, 63.6% had KJOC scores below the average for the group. The KJOC scores for U14 ($p = 0.04$) and U15 ($p = 0.004$) were significantly different from U19 (Figure 3.3).

Table 3.3: KJOC scores across the age groups

	Total (n= 83)	U14 (n= 21)	U15 (n= 24)	U16 (n= 15)	U19 (n= 23)
KJOC Score	82.5 ± 15	79.7 ± 17.4	90 ± 7.5	83.8 ± 9.6	76.5 ± 18.3
Impingement Tests	D - 22 ND - 11	D - 9 ND - 4	D - 4 ND - 2	D - 3 ND - 3	D - 6 ND - 2

**D – Dominant; ND – Non-dominant*

Figure 3.3: KJOC scores that were significantly different across the age groups



○: *Value falls within 3 standard deviations*
*: *Value falls outside 3 standard deviations*

3.7.3 Throwing performance

The average throwing speed for the group was 23.7mph ± 6.7 and the accuracy score was 2.3 ± 1.5 (Table 3.4).

Table 3.4: Average TS and TA results across the age groups

	Total (n= 83)	**U14 (n= 21)**	**U15 (n= 24)**	**U16 (n= 15)**	**U19 (n= 23)**
Throwing speed (mph)	23.7 ± 6.7	16.4 ± 4.4	26.3 ± 2.2	27.1 ± 2.3	28.2 ± 2.4
Throwing accuracy (max= 8)	2.3 ± 1.5	1.7 ± 1	2.8 ± 1.8	1.9 ± 1.3	2.9 ± 1.4

Various musculoskeletal variables were analysed and the four assumptions (normality, linearity, lack of multi-collinearity and homoscedasticity) required for a MRA, were met. The correlation coefficients of the independent variables can be seen in Table 3.5. The variables significantly correlated with TS and included in the MRA model, can be seen in Table 3.6 while the variables significantly correlated with TA and included in the MRA model, can be seen in Table 3.7.

Table 3.5: Correlation coefficients of the independent variables

		Throwing Performance (TP)			
		Throwing Speed (TS)		Throwing Accuracy (TA)	
Variable Tested	**Side**	r	p	r	p
Anthropometrics					
Age group	n/a	0.694	< 0.001	0.215	0.051
Mass	n/a	0.039	0.729	-0.12	0.278
Standing height	n/a	0.212	0.054	0.155	0..163
Sitting height	n/a	0.394	< 0.001	0.307	0.005
Range of Motion					
GH Internal Rotation ROM	D	-0.008	0.941	-0.277	0.011
	ND	0.004	0.971	-0.208	0.059
GH External Rotation ROM	D	-0.046	0.682	0.178	0.107
	ND	-0.113	0.31	0.028	0.803
GIRD	n/a	-0.019	0.862	0.015	0.89
ERG	n/a	0.173	0.118	0.125	0.259
TROM difference	n/a	0.07	0.528	0.042	0.709
Flexibility					
Pectoralis minor length	D	0.427	< 0.001	0.191	0.084
	ND	0.539	< 0.001	0.163	0.141
Strength					
GH Internal Rotators	D	0.185	0.095	0.006	0.956
	ND	0.188	0.089	0.164	0.139
GH External Rotators	D	0.207	0.061	0.039	0.727
	ND	0.355	< 0.001	0.096	0.387
GHER:GHIR ratio	D	0.036	0.749	0.047	0.671
	ND	0.161	0.146	-0.065	0.558
Serratus anterior strength	D	0.431	< 0.001	0.26	0.017
	ND	0.321	0.003	0.221	0.045
Upper trapezius strength	D	0.51	< 0.001	0.29	0.008
	ND	0.599	< 0.001	0.279	0.011
Lower trapezius strength	D	0.04	0.722	0.099	0.371
	ND	0.106	0.342	0.048	0.669

Gluteus medius strength	D	0.158	0.154	0.06	0.587
	ND	0.229	0.038	0.056	0.613
Upward Scapula Rotation					
0° of GH abduction	D	0.234	0.033	0.144	0.193
	ND	0.37	< 0.001	0.078	0.486
45° of GH abduction	D	0.116	0.297	0.09	0.419
	ND	0.175	0.113	0.05	0.654
90° of GH abduction	D	0.367	< 0.001	0.221	0.044
	ND	0.413	< 0.001	0.169	0.128
135° of GH abduction	D	0.422	< 0.001	0.231	0.036
	ND	0.401	< 0.001	0.203	0.066
Other					
Medicine ball throws	n/a	0.063	0.571	-0.011	0.922
KJOC score	n/a	-0.026	0.813	0.149	0.18

**D – Dominant; ND – Non-dominant*
**r = correlation coefficient; p = probability value*

3.7.3.1 Throwing speed (TS)

Based on these bivariate analyses, eight of the most relevant variables (age group, dominant PML, non-dominant PML, dominant UT strength, non-dominant UT strength, dominant SA strength, dominant USR at 135° and non-dominant USR at 90°) that were significantly correlated with TS (p <0.05) and had a value of at least r= 0.3 as their correlation coefficient[316], were selected. However, as previously stated, a cut-off of 5.0 was set for VIF to avoid multicollinearity. There were two variables (dominant UT strength and non-dominant UT strength) that had high VIF values of 6.3 and 9.2 respectively. The variable with the higher VIF value (non-dominant UT strength – VIF 9.2) was removed to ensure the model satisfied the assumptions of MRA. The remaining seven variables were then added to a multivariate linear regression, following the 'rule' of 10 cases per independent variable[317,318]. The outcome of the regression showed that the seven variables combined accounted for 42.6% variance in the TS test (Table 3.6). From the multiple regression model, age group remained the only variable significantly correlated (p <0.001) with TS. Therefore, as the girls moved up from one age group to the next, an increase of 1.8mph in TS can be anticipated.

Table 3.6: Variables significantly correlated with TS and included in the MRA

Variables included	Coefficient - standardised	Coefficient – unstandardised (95% confidence interval)	Std. error	Significance (p-value)	VIF value
Throwing Speed ***(R^2 = 0.426)***					
Age group	0.62	**1.78**	0.49	**<0.001**	3.81
D PML	-0.13	-0.44	0.53	0.41	3.45
ND PML	0.23	0.72	0.49	0.14	3.02
D UT strength	0.23	0.01	0.01	0.18	3.65
D SA strength	-0.03	-0.002	0.01	0.83	2.94
D USR 135°	-0.23	-0.13	0.1	0.22	4.43
ND USR 90°	-0.07	-0.06	0.13	0.63	2.75

**D – Dominant; ND – Non-dominant*

The standardised residuals were plotted against the standardised predicted value (Appendix K). When a Gaussian Loess line was fit to this scatter plot, it was observed to have minimal gradient suggesting that an increase or decrease in predicted value did not significantly change the residuals. Hence, we can infer that our model satisfied the homoscedastic assumption of MRA.

3.7.3.2 Throwing accuracy (TA)

Based on these bivariate analyses, eight of the most relevant variables that were significantly correlated with TA and had a value of at least 0.3 as their correlation coefficient[316], were chosen. However, only five variables (sitting height, dominant GH IR ROM, dominant UT strength, non-dominant UT strength and dominant SA strength) had R values of > 0.3. Again, a cut-off of 5.0 was set for VIF and again, there were two variables (dominant and non-dominant UT strength) that had high VIF values of 6.1 and 7.1 respectively. The variable with the higher VIF value was removed (non-dominant UT – VIF 7.1). The remaining four variables were added to a MRA, satisfying the 'rule' of 10 cases per independent variable[317,318]. The outcome of the regression showed that the above four variables combined accounted for 17% variance in the TA test (Table 3.7). From the Spearman correlation, all variables were significantly correlated (p <0.001), however, after adding all variables to the MRA, dominant GH IR ROM remained the only variable significantly correlated (p <0.001) with

TA. Therefore, for every 1 degree decrease in GH IR ROM, one can expect an increase of 0.27 in target accuracy.

When the standardised residuals were plotted against the standardised predicted value (Appendix L), there was no major gradient when a Gaussian Loess Line was fit to the data. Therefore, the model is deemed to be homoscedastic, satisfying the fourth and final MRA condition.

Table 3.7: Variables significantly correlated with TA and included in the MRA

Variables included	Coefficient – standardised B	Coefficient – unstandardised B (95% confidence interval)	Std. error	P-value	VIF value
Throwing Accuracy (R^2 = 0.171)					
Sitting height	0.14	0.05	0.05	0.27	1.53
D UT strength	0.08	0.001	0.003	0.64	2.65
D SA strength	0.16	0.003	0.003	0.35	2.53
D GH IR ROM	-0.27	**-0.05**	0.02	**0.02**	1.09

**D – Dominant*

3.7.4 Differences in musculoskeletal profile across the age groups

3.7.4.1 Scapular stabiliser and gluteal muscle strength

Serratus anterior (SA)

Overall and on average, the dominant side (305.84N ± 82.03) had slightly weaker SA muscle strength compared to the non-dominant side (317.81N ± 76.95), except in the U19 age group, where the dominant side score was marginally higher (398.48N ± 63.74 vs 397.39N ± 67.32) (Table 3.8). However, no significant side-to-side differences in SA strength scores were observed. Both the dominant and non-dominant scores for U14, U15 and U16 were significantly lower ($p < 0.01$) than the U19 scores (Figure 3.4 and 3.5).

Upper trapezius (UT)

In the two younger age groups (U14 and U15), slightly stronger dominant UT scores were observed compared to the non-dominant side. However, in the older age groups (U16 and U19), the opposite was evident, where slightly stronger non-dominant UT scores were noted, compared to the dominant side (Table 3.8). No significant side-to-side differences in UT strength scores were observed. Both the dominant and non-dominant scores for U14, U15 and U16 were significantly lower ($p < 0.01$) than the U19 scores (Figure 3.6 and 3.7).

Lower trapezius (LT)

On average, the dominant side (78.59N ± 24.76) displayed stronger LT strength compared to the non-dominant side (68.3N ± 22.44). Significant side-to-side differences ($p = 0.008$) in LT strength were observed, where the dominant side displayed higher strength values. This was consistently found across all age groups (Table 3.8). The dominant LT strength scores for U15 were significantly higher ($p = 0.03$) than U19, while the non-dominant scores for U14 were significantly lower ($p = 0.04$) than U15 (Figure 3.8 and 3.9).

Gluteus medius (GM)

Overall and on average, the dominant side (272.79N ± 65.33) displayed slightly stronger GM muscle strength compared to the non-dominant side (265.4N ± 73.41), except in the U15 age group, where the non-dominant side score was slightly higher (236.56N ± 38.39 vs 233.38N ± 38.73) (Table 3.8). However, no significant side-to-side differences in GM strength scores were observed. The dominant and non-dominant scores for U14 (D: p= 0.003; ND: p= 0.01), U15 (D and ND: p <0.01) and U16 (D and ND: p <0.01) were significantly lower than U19 (Figure 3.10 and 3.11).

Table 3.8: Scapula stabiliser and GM strength scores for dominant and non-dominant sides across the age groups

	Total (n= 83)	U14 (n= 21)	U15 (n= 24)	U16 (n= 15)	U19 (n= 23)
D SA	305.8N ± 82	262.8N ± 68.5	281N ± 48.4	263.9N ± 51.5	398.5N ± 63.7
ND SA	317.8N ± 77	288.6N ± 62	292.6N ± 47	277N ± 62.4	397.4N ± 67.3
D UT	301.2N ± 100.3	240.2N ± 77.1	270.7N ± 52.8	246.8N ± 38.4	424.1N ± 76.7
ND UT	300.3N ± 103	228.4N ± 77.2	265.9N ± 42	251N ± 30	434N ± 71.2
D LT	78.6N ± 24.8	72.7N ± 20.1	93N ± 30.1	75N ± 13.8	71.3N ± 22.9
ND LT	68.3N ± 22.4	61.7N ± 21.5	79N ± 25.5	68N ± 15.6	63.31N ± 20.6
D GM	272.8N ± 65.3	268.8N ± 62.1	233.4N ± 38.7	235N ± 37.3	342.2N ± 47.3
ND GM	265.4N ± 73.4	263.4N ± 46.2	236.6N ± 38.4	212.1N ± 37.4	332N ± 90.7

**D – Dominant; ND – Non-dominant*

Scapula stabiliser and GM strength scores (dominant and non-dominant) that were significantly different between the age groups

Figure 3.4: Dominant SA strength

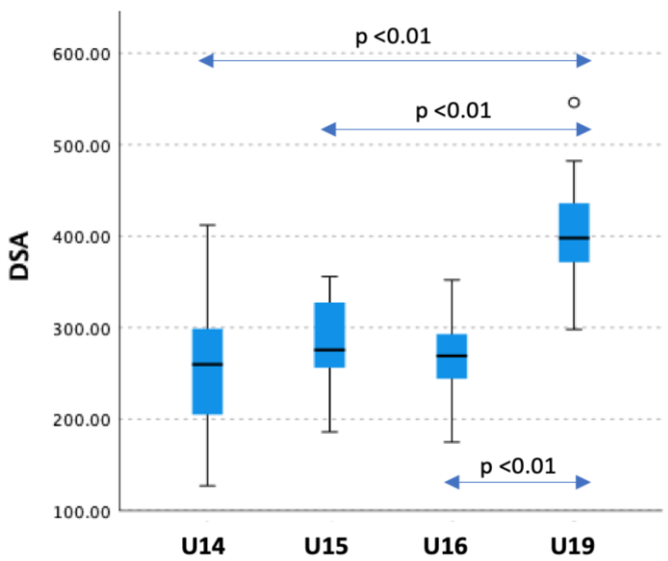
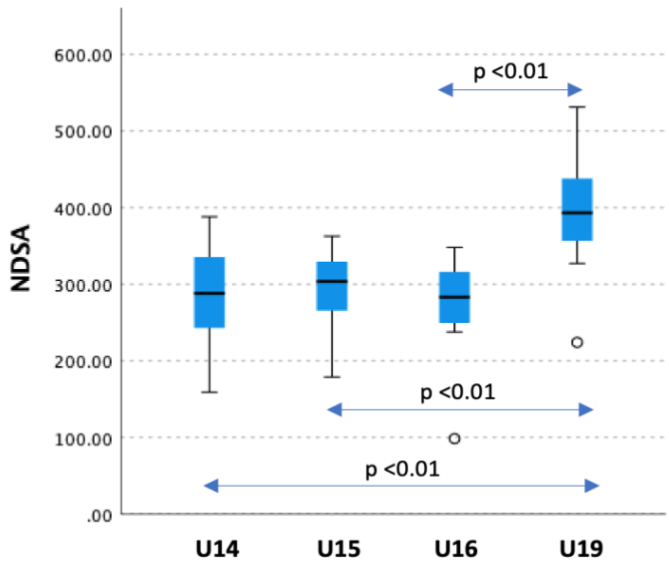


Figure 3.5 : Non-dominant SA strength



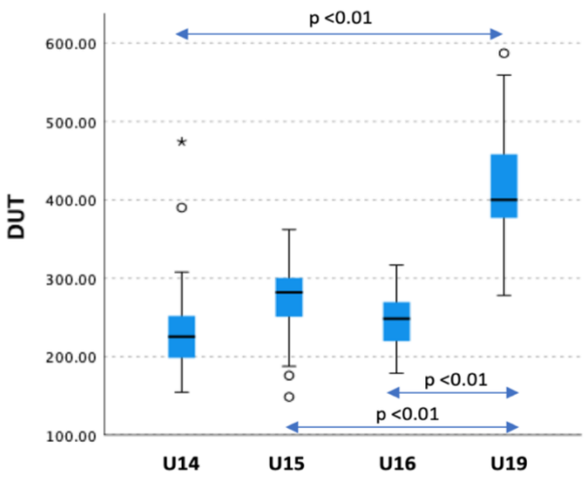


Figure 3.6: Dominant UT strength

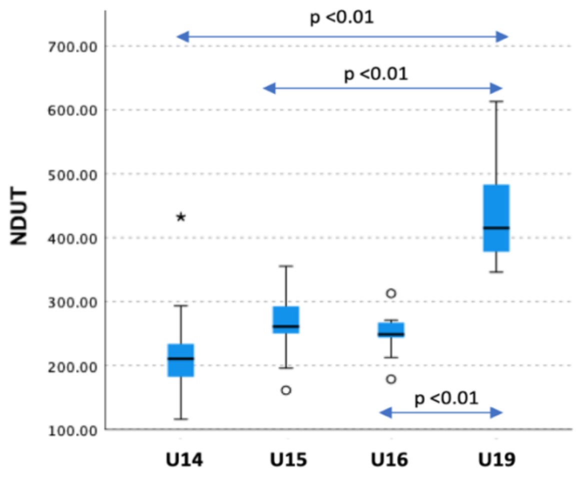


Figure 3.7: Non-dominant UT strength

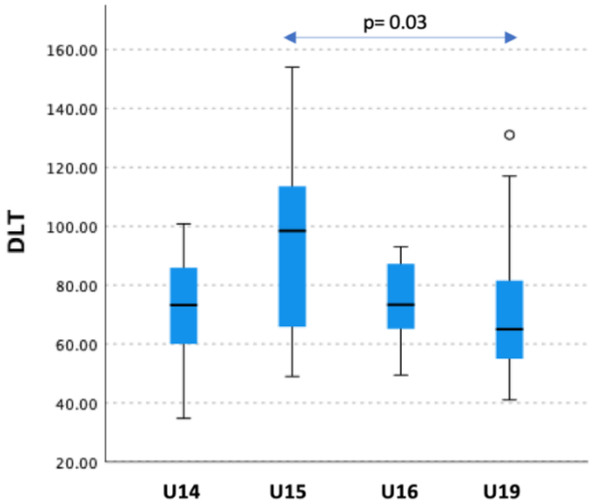


Figure 3.8: Dominant LT strength

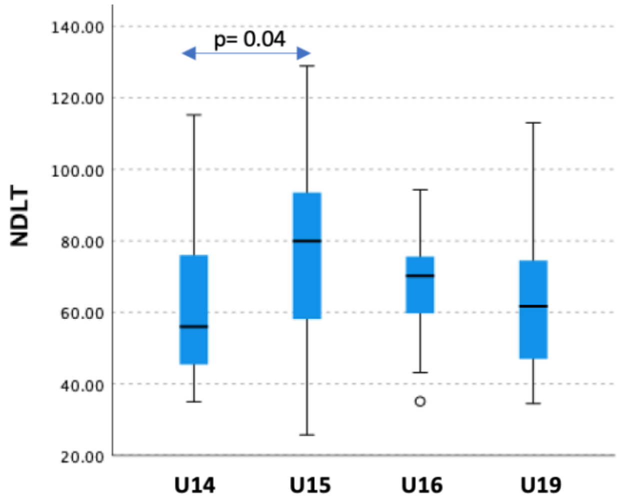


Figure 3.9: Non-dominant LT strength

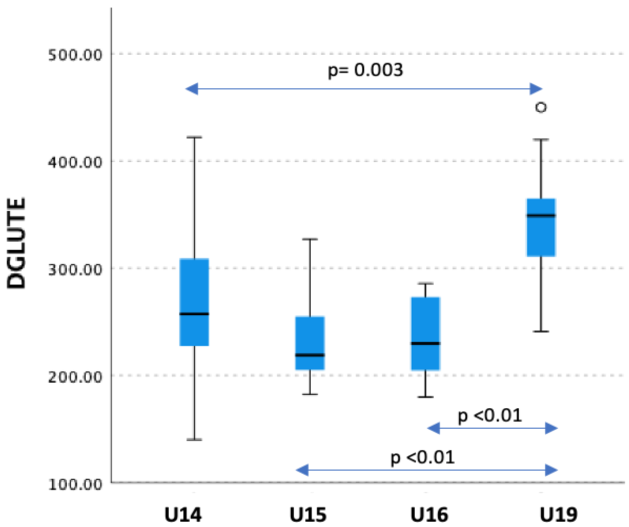


Figure 3.10 Dominant GM strength

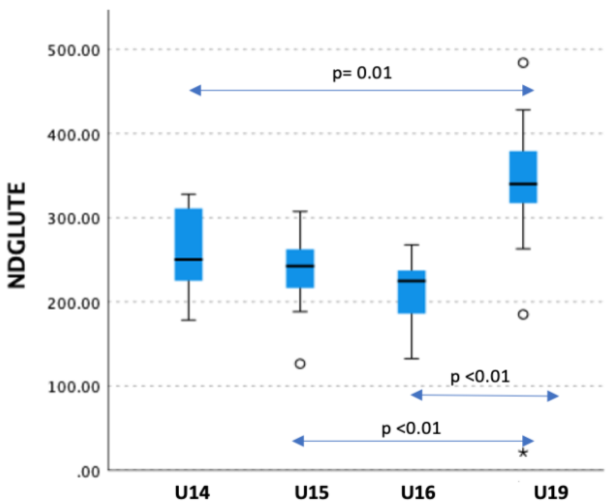


Figure 3.11: Non-dominant GM strength

○: Value falls within 3 standard deviations
**: Value falls outside 3 standard deviations*

3.7.4.2 Upward scapula rotation (USR) range of motion

Across all groups, the resting scapula position was downwardly rotated for both the dominant (-4.12° ± 6.24) and non-dominant (-4.3 ± 5.52) sides. USR increased across all groups as the arm moved further into GH abduction, from 0°, to 45°, to 90° and to 135° (Table 3.9). On average, the dominant side displayed slightly more upward rotation at 0°, but slightly less upward rotation at 45°, 90° and 135°, compared to the non-dominant side. However, there were no significant side-to-side difference in USR scores. The non-dominant USR 0° scores for U14 and U15 were significantly different ($p < 0.05$) from U19. The dominant and non-dominant USR 90° as well as USR 135° scores for U14, U15 and U16 were significantly different ($p < 0.05$) from U19 (Figure 3.12-3.16).

Table 3.9: USR scores across the age groups

	Degrees of GH abduction	Total (n= 83)	U14 (n= 21)	U15 (n= 24)	U16 (n= 15)	U19 (n= 23)
Dominant	**0°**	-4.12° ± 6.24	-5.7° ± 7.46	-5.47° ± 6.27	-4.26° ± 5.67	-1.16°± 4.43
	45°	-0.64° ± 5.03	-1.57° ± 5.2	-0.83° ± 4.94	-0.81° ± 4.57	0.54° ± 5.35
	90°	7.27° ± 4.55	5.46° ± 4.1	5.51° ± 3.16	6.53° ± 2.31	11.25° ± 4.98
	135°	17.26° ± 9.74	13.43° ± 8.64	11.44° ± 1.93	12.17° ± 2.23	30.14° ± 6.06
Non-dominant	**0°**	-4.3° ± 5.52	-6.77° ± 3.98	-6.92° ± 5.22	-3.1° ± 5.61	-0.1° ± 4.24
	45°	-0.62° ± 4.79	-2.46° ± 3.66	-2.1° ± 4.23	0.33° ± 3.89	1.95° ± 5.64
	90°	7.45° ± 6.31	4.93° ± 4.22	3.33° ± 3.34	6.55° ± 2.49	14.64° ± 6.13
	135°	17.85° ± 10.7	13.4° ± 8.86	11.4° ± 2.81	12.17° ± 2.02	32.37° ± 6.21

USR scores at 0°, 90° and 135° of GH abduction (dominant and non-dominant) that were significantly different between the age groups

Figure 3.12: Non-dominant USR at 0°

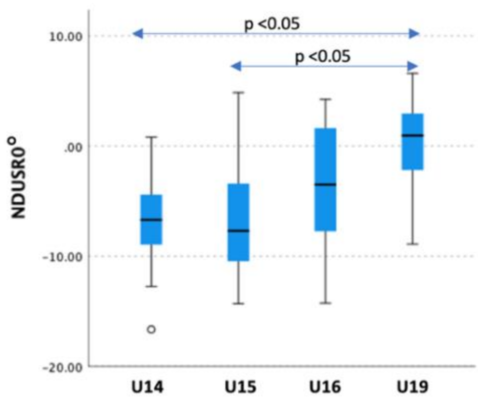


Figure 3.13: Dominant USR at 90°

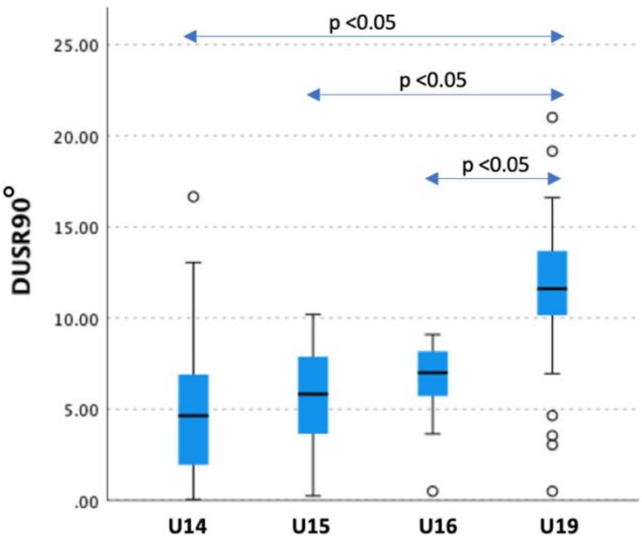


Figure 3.14: Non-dominant USR at 90°

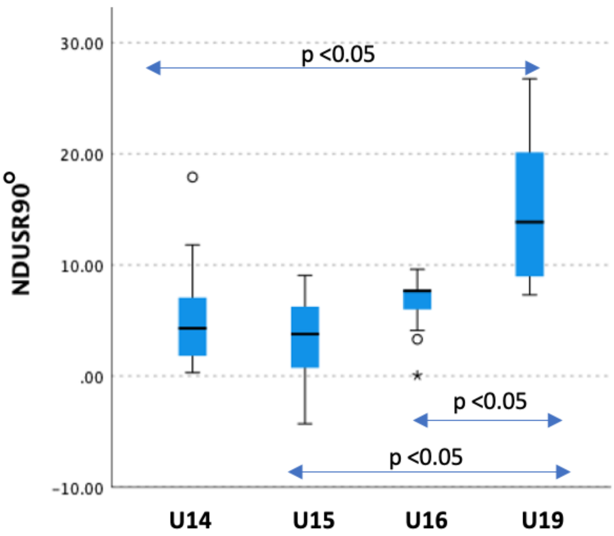


Figure 3.15: Dominant USR at 135°

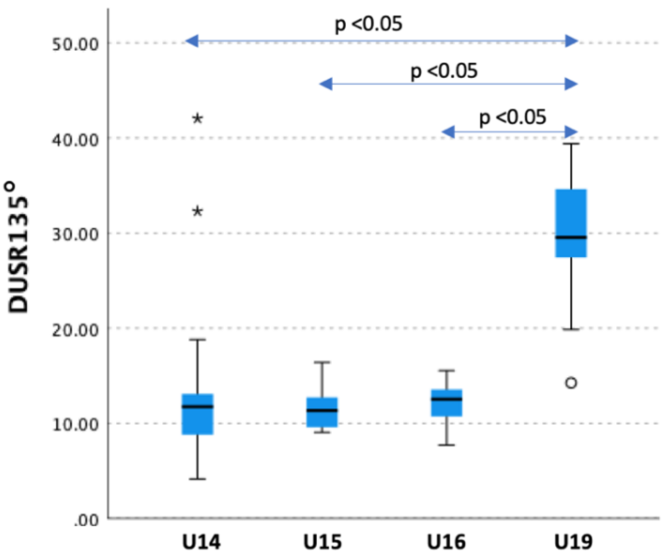
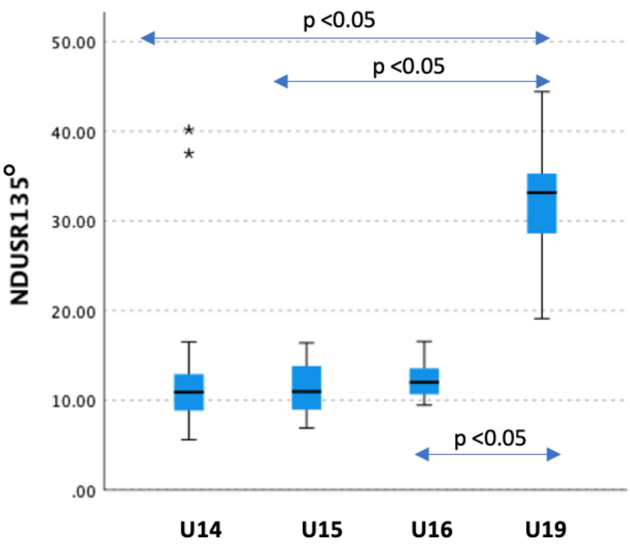


Figure 3.16: Non-dominant USR at 135°



○: *Value falls within 3 standard deviations*
*: *Value falls outside 3 standard deviations*

3.7.4.3 Flexibility

On average, the dominant PML (10.24cm ± 1.72) was less than the non-dominant side (10.59cm ± 1.76). This was consistently found across all age groups (Table 3.10). There were no significant side-to-side asymmetries observed, however, the dominant and non-dominant pec minor length scores for U14 ($p < 0.05$), U15 ($p < 0.05$) and U16 (D: $p < 0.05$; ND: $p = 0.007$) were significantly lower than U19 (Figure 3.17 and 3.18).

Table 3.10: PML scores across the age groups

	Total (n= 83)	U14 (n= 21)	U15 (n= 24)	U16 (n= 15)	U19 (n= 23)
D PML (cm)	10.2 ± 1.7	9.3 ± 1.2	9.3 ± 0.9	9.7 ± 1.4	12.3 ± 0.9
ND PML (cm)	10.6 ± 1.8	9.4 ± 1.4	9.7 ± 1.2	10.7 ± 1.3	12.6 ± 0.9

**D – Dominant; *ND – Non-dominant*

PML scores (dominant and non-dominant) that were significantly different between the age groups

Figure 3.17: Dominant PML

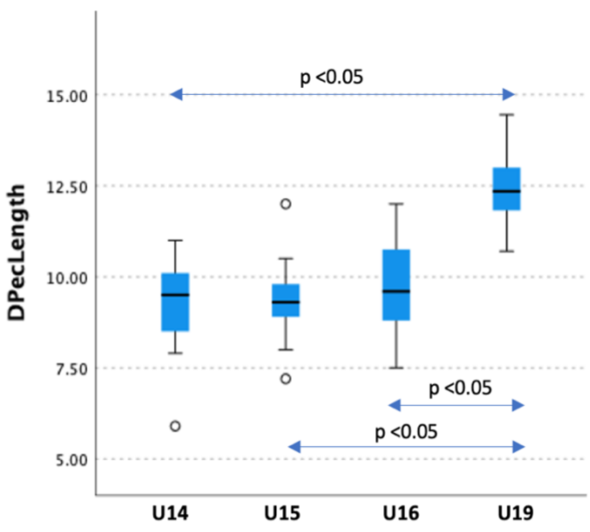
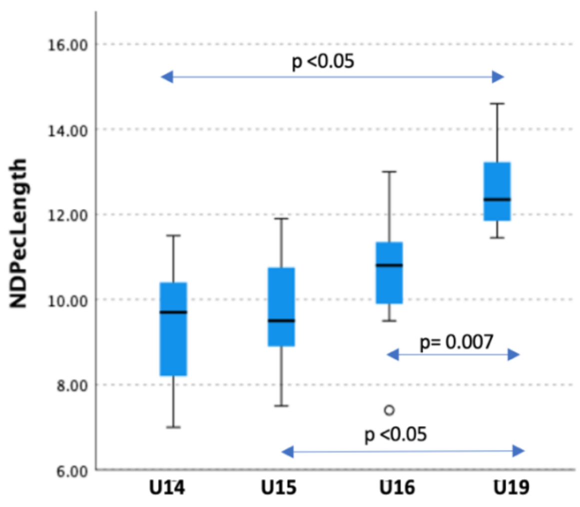


Figure 3.18: Non-dominant PML



○: *Value falls within 3 standard deviations*
*: *Value falls outside 3 standard deviations*

3.7.4.4 Glenohumeral rotator strength

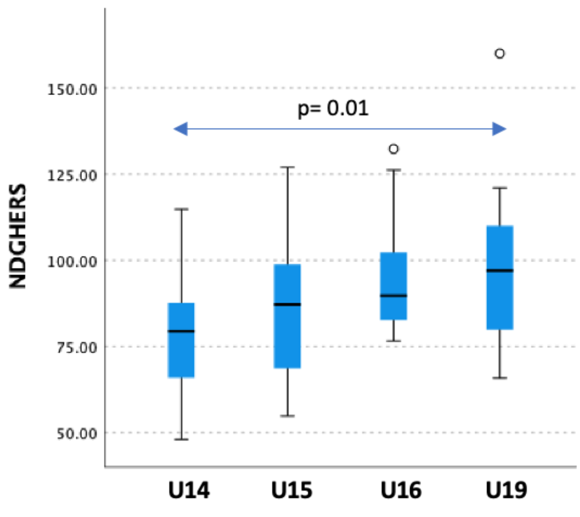
There were no statistically significant side-to-side difference in GH internal and external rotation strength. However, the dominant shoulder displayed slightly greater internal and external rotator strength compared to the non-dominant side, except in the U15 age group, where the non-dominant external rotators were in fact slightly stronger than the dominant ones (Table 3.11). The average GHER:GHIR strength ratio was 0.8 (80%). The GH internal rotator strength scores (dominant and non-dominant) were not significantly different across the ages, however, the non-dominant GH external rotator strength scores for U14, were significantly lower (p= 0.01) than U19.

Table 3.11: GH internal and external rotator strength scores across the age groups

	Total (n= 83)	U14 (n= 21)	U15 (n= 24)	U16 (n= 15)	U19 (n= 23)
D GH internal rotators (N)	114.3 ± 25.4	106.2 ± 15.2	117.2 ± 19.7	111.4 ± 24.1	120.6 ± 36.1
ND GH internal rotators (N)	110.3 ± 23.2	101.6 ± 18.8	111.6 ± 21.6	110 ± 19.9	117.1 ± 28.6
D GH external rotators (N)	90 ± 22.1	83 ± 19.7	83.3 ± 21.4	98.8 ± 27.4	97.7 ± 17.4
ND GH external rotators (N)	88.8 ± 20.2	77.7 ± 17	85.8 ± 18.7	95.7 ± 18.2	97.5 ± 21
D GHER:GHIR strength ratio	0.8 ± 0.2	0.8 ± 0.2	0.7 ± 0.1	0.9 ± 0.2	0.9 ± 0.4
ND GHER:GHIR strength ratio	0.8 ± 0.2	0.8 ± 0.2	0.8 ± 0.2	0.9 ± 0.1	0.9 ± 0.2

**D – Dominant; ND – Non-dominant*

Figure 3.19: GH external rotator strength scores (non-dominant) that were significantly different between the age groups



O: Value falls within 3 standard deviations
**: Value falls outside 3 standard deviations*

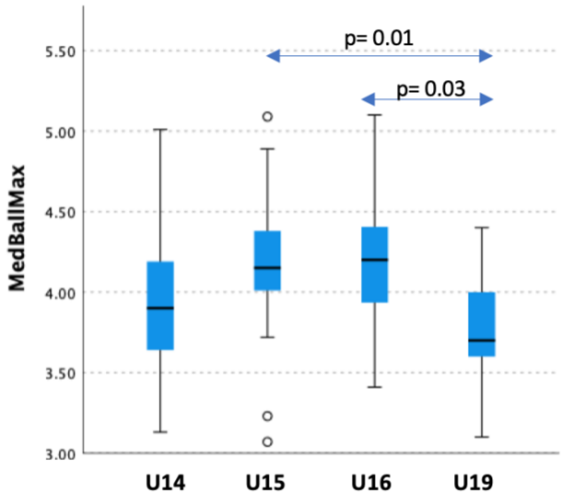
3.7.4.5 Medicine ball throws

The U16 age group was able to throw the medicine ball the furthest (4.22m ± 0.51), followed by the U15s (4.16m ± 0.45), U14s (3.93m ± 0.47) and finally the U19s (3.8m ± 0.34), who demonstrated the poorest scores (Table 3.12). The medicine ball scores for U15 ($p = 0.01$) and U16 ($p = 0.03$) were significantly higher than U19 (Figure 3.20).

Table 3.12: Medicine ball throw scores across the age groups

	Total (n= 83)	U14 (n= 21)	U15 (n= 24)	U16 (n= 15)	U19 (n= 23)
Max Score (m)	4.01 ± 0.46	3.93 ± 0.47	4.16 ± 0.45	4.22 ± 0.51	3.8 ± 0.34

Figure 3.20: Medicine ball throw scores that were significantly different between the age groups



○: *Value falls within 3 standard deviations*
*: *Value falls outside 3 standard deviations*

3.7.5 Side-to-side asymmetries

3.7.5.1 Glenohumeral rotation range of motion

There were significant side-to-side differences in GH IR ROM (p <0.001) and GH ER ROM (p <0.001), where reduced GH IR ROM and increased GH ER ROM on the dominant side was recorded. The changes in both dominant and non-dominant GH IR ROM and GH ER ROM, across the age groups, were not statistically significant.

The U19 age group had the lowest GIRD (4° ± 6.34), while the U15 girls had the highest GIRD (5.75° ± 6.8). Overall, there were three participants who presented with GIRD >20°, one in U14, U15 and U16 and with KJOC scores of 89.5, 91.5 and 84.5 respectively. The U15 age group had the lowest ERG (3.46° ± 9.73), while the U19 age group had the highest ERG (7.96° ± 7.88). The U15 group recorded the lowest dominant TROM, while the U14 group recorded the highest. On the non-dominant side, the U16 group recorded the lowest TROM values, while the U14s recorded the highest (Table 3.13).

Table 3.13: GH ROM values across the age groups

	Total (n= 83)	U14 (n= 21)	U15 (n= 24)	U16 (n= 15)	U19 (n= 23)
D GH IR ROM	58.8° ± 8.3	58.8° ± 8.4	59.3° ± 9.4	57.2° ± 6.2	59.2° ± 8.5
ND GH IR ROM	63.5° ± 7.7	63.6° ± 5.9	65.1° ± 8.9	61.4° ± 8	63.2° ± 7.9
D GH ER ROM	106.1° ± 11.3	109.4° ± 10.4	102.4° ± 14.3	106.1° ± 8.3	107° ± 9.8
ND GH ER ROM	99.9° ± 10.1	102.4° ± 12	98.9° ± 8.8	99.3° ± 8.5	99° ± 10.7
D TROM	164.9° ± 12.4	168.2° ± 16.3	161.7° ± 13.3	163.3° ± 8.9	166.2° ± 8.4
ND TROM	163.4° ± 10.8	166° ± 12.5	164° ± 11	160.6° ± 9.1	162.2° ± 10.2
GIRD	4.8° ± 7.8	4.9° ± 9	5.8° ± 6.8	4.2° ± 10	4° ± 6.3
ERG	6.2° ± 8.3	7° ± 5.5	3.5° ± 9.7	6.8° ± 9.2	9° ± 7.9

**D – Dominant; ND – Non-dominant*

3.7.5.2 Lower trapezius strength:

There were significant side-to-side differences in LT strength (p= 0.008), with the dominant side recording significantly higher strength values compared to the non-dominant side (Table 3.8).

3.8 Discussion

This study contributes to a limited research field exploring the musculoskeletal profile of female adolescent elite water polo players and its influence on throwing performance (TP). The primary outcome of this study established that age group was the only factor significantly correlated to throwing speed (TS), while dominant GH IR ROM was the only factor significantly correlated to throwing accuracy (TA). There were a number of differences between the age groups for scapular stabiliser and GM strength, USR, PML and medicine ball throws. There were less side-to-side asymmetries for this group, with GH rotational ROM and lower trapezius strength being the only variables to demonstrate significant asymmetry.

This is one of very few studies that has investigated TS in female adolescent elite water polo players, aged 14-19 years. It is well documented that adolescents experience a rapid growth spurt until PHV is reached[12]. Given the link between biological maturation and performance level in sports[319], PHV is a valuable indicator of the adolescent athlete's phase of maturation[12]. Mean PHV was calculated as 10.67 years old in this study. This is normal for this age group population as PHV is reached between the ages of 9.3 and 15 years for females[320,321]. 100% of the population had reached PHV, which confirms group homogeneity.

3.8.1 The musculoskeletal profile of female adolescent elite water polo players

The 'thrower's paradox' that is typically described in baseball pitchers, describes an athlete with an ERG and concomitant GIRD at 90° of GH abduction in the throwing arm[41,126,193,210,219,220,223,224,226–229], while maintaining TROM to within a 5° difference[41,218]. While there are some similarities, female adolescent water polo players appear to present differently to other overhead throwing athletes.

The water polo players in this study presented with an increase in GH ER ROM and ERG, mirroring the findings in other water polo players[39,196], swimmers[261] and baseball pitchers[38,322], but did not exhibit a GH IR ROM loss or GIRD that is typically seen amongst overhead athletes[5,11,223]. They do not demonstrate a decrease in GH IR ROM to the same extent as other land-based overhead athletes[102,126,166,195,210,213,219,220,223,228,251,252,262,270,278,323], which is positive from an injury perspective[11,106,186,276,278,291,323–328]. The GH IR ROM scores of 58.8° in the throwing arm were similar to some water polo players[106,196,253] and some baseball pitchers[38,224,225,229] where the GH IR ROM also appears to be somewhat preserved, with values ranging between 55.5° and 62.6°. The scores were also comparatively high to those seen in other cohorts of baseball pitchers, where values fell below 45°[219,220,228,251,252] as well as in water polo[39,40,108,255], swimming[329], tennis[323] and cricket[102], where values ranged from 39-48.8°. A possible explanation for this could be that the participants in our study have not played water polo for as many years, not allowing enough time or workload for the inherent bony adaptions to occur[251,270], such as humeral retroversion, which would result in a further GH IR ROM loss[330]. Alternatively, these athletes may possess an inherent hypermobility of the shoulder region.

Deficits in dominant GH IR ROM compared to the contralateral side, better known as GIRD, have been associated with increased injury risk in throwing athletes[41,235,331]. Our cohort only exhibited a slight GIRD of 4.8°, mirroring the findings of Jameson (2020)[106] and de Assis Couto et al. (2020)[108] in adolescent water polo players, which is below both the >10° definition[255] as well as the <20° recommendation for reduced injury risk[5,9,39,223,323,332] and also the GIRD values observed in other water polo players[255].

An increase in dominant GH ER ROM has been associated with improved TP amongst overhead athletes[5,201]. In the current study, the dominant GH ER ROM scores (106.1°) are in-keeping with that of other overhead athletes, including adolescent water polo players[39,196], swimmers[261] and baseballers[38,322], suggesting a potential adaptation. A greater GH ER ROM allows for a greater wind-up (as part of the backswing phase) and a greater range through which to gain maximal TS prior to ball release[20,146]. A possible mechanism behind this adaptation, is the fact that the repetitive overhead throwing motion may cause inferior GH ligament stretching and a resultant ERG[40]. In this study, the GH ER ROM values were markedly higher than those found in another cohort of adolescent water polo players[108], but much lower than those found in male adolescent baseball pitchers[333]. Further, our population also displayed an increase in non-dominant GH ER ROM (99.9°), which may reflect two potential phenomena. Firstly, the swimming component of water polo is significant and has resulted in bilateral adaptation in GH ROM evident in swimmers[261,329]. Secondly, water polo may pre-select hypermobile athletes. Participants in the present study largely preserve their TROM values and exhibit symmetrical TROM scores that align with the findings of another water polo study[254]. Other studies have shown water polo players to have either only symmetrical TROM scores[39,106,108,253] or only preserved TROM on the dominant side[196]. Swimmers appear not to preserve TROM, but do demonstrate symmetrical TROM scores[261,329]. The TROM values in this study were higher than other cohorts of water polo players[39,106,108,255] and cricketers[102] due to the maintained GH IR ROM values. Unlike other overhead throwers[195,262,269], the TROM was more symmetrical likely due to the swimming component of water polo, which requires bilateral shoulder ROM.

Musculoskeletal asymmetries between dominant and non-dominant sides are commonly seen amongst overhead athletes[223,334,335], yet only GH IR ROM, GH ER ROM and LT strength asymmetries were noted in our population. This may be due to the biomechanical demands of this sport, which differ greatly to land-based overhead sporting requirements[39,110,111,115]. While water polo players shoot with the dominant arm, defensive wrestling[112] and the swimming action are bilateral activities[43].

Upward Scapula Rotation (USR) is affected by several factors, including SA[206,207], UT[7] and LT[30] activation, posterior capsular tightness[230] and PML[7,14,24,122,201,208,212,268]. Findings amongst overhead athletes appear to be diverse. In general, overhead throwers are proposed to have increased upward scapula rotation from 0° to 180° of GH elevation on the dominant side[336]. However, similar scores for the dominant and non-dominant side were found in our cohort, mirroring the findings of other water polo players[106,196], which reflects the bilateral adaptations of water polo players. Participants in the current study presented with a downwardly rotated scapula at rest, supporting other water polo[106,196] and cricket[102] findings but conflicted with findings in baseball [38,230,238], tennis[7], swimming[337] as well as in another cricket population[35], where participants presented with an upwardly rotated scapula at rest. This resting position of downward scapula rotation observed in the current study was found to increase with increasing degrees of GH elevation, mirroring the findings of other overhead athletes, where the USR values at the end stages of GH elevation were similar[106,196]. Downward scapula rotation may be as a result of a lengthened UT, shortened rhomboids or a shortened pectoralis minor muscle, which would then require the scapular stabilisers to work particularly hard towards the end stages of elevation. The UT muscle has often been found to be weak but displays a burst of increased activity in the later stages of GH elevation[28,338,339]. The length of the UT and rhomboids were not assessed in the current study, however, PML was evaluated, and no significant side-to-side asymmetries were observed in this population, although, the dominant side tended to have a slightly shorter length. These findings are consistent with that of other literature in water polo players[106,196] as well as other overhead athletes such as tennis players[7], baseball pitchers[240] and cricketers[35]. Insufficient normative data exists for PML in female water polo players. However, compared to other overhead athletes including female swimmers[212], these female adolescent water polo players appear to have dominant PML measurements (10.2 cm) that fall on the lower end of a range of values that range between 9.54-15.88cm[7,35,102,106,196,212,240,253,340,341]. This indicates that they are on the shorter side and could be a contributing factor towards the downwardly rotated scapula at rest that is present in this cohort.

The water polo players in the present study presented with symmetrical SA and UT strength scores, which again reflects the bilateral nature of water polo as a sport, where players are required to both swim and shoot. Swimmers have strong scapular stabilising muscles[263], mirroring the results of the present study. The bilateral scapula stabiliser strength scores were much higher than those recorded amongst other water polo players[106,196], swimmers[337], tennis players[7] as well as baseball pitchers[258]. These findings could be due to the aquatic nature of water polo which demands a higher contribution from the upper limb as a result of the unstable base provided by the water. In addition, the upper limbs are used for multiple overhead activities in addition to throwing. Asymmetrical LT strength scores were noted for this population, confirming the findings of two other water polo studies[106,196].

The increased GH internal rotator strength compared to external rotator strength scores observed in this study is a common finding amongst the general population as well as overhead athletes[14,35,106,158,159,196,203,231,258,342]. It is a typical adaptive response to both swimming and throwing[343]. The GH internal and external rotator strength scores were similar to that of adolescent tennis players[323] and adolescent female swimmers[344]. These scores were also much stronger when compared to another cohort of club-level, adult, female water polo players[158] as well as a cohort of high-school males[106]. For overhead athletes, a GHER:GHIR strength ratio of 66-75% is deemed to be the norm for adequate joint stability and reduced injury risk[15,249]. This ratio has been described in the throwing population and findings are diverse, with an aquatic-based study not reporting any imbalances[344], while other aquatic as well as land-based studies have observed small[106,254,342] to large discrepancies[196]. The participants in the present study exhibited a GHER:GHIR strength ratio of 0.8 bilaterally, which is same as those suggested for non-pathological shoulders (± 0.8) as well as higher than the 0.74 ratio recommended for healthy women[345]. These scores matched those reported in studies in water polo[106,254], swimming[342] and cricket[102], but were higher than other water polo[159,196,203,257], tennis[269,272], baseball[258] and swimming studies[265,346], where a low imbalanced ratio in the throwing arm was reported. It is not clear whether the higher ratio observed in this study reflects an adaptation in this group or whether this group had a relative weakness of the GH internal rotators.

The KC principle maintains that it is the contraction of the larger muscles of the proximal segments that result in the intensified angular velocity of the smaller distal segments. The greater the number of body segments utilised sequentially, the higher the resultant velocity of the ball at release[347]. It has been shown that it is trunk rotation, hip abduction (which includes involvement of the GM), and actions of the shoulder, followed by the elbow and wrist that contribute most to ball speed development in the overhead throw[348]. This group of female adolescents presented with strong GM scores, which were similar to that of some male, amateur cricket players[35], but much higher than another cohort of male cricketers[102]. This may be due to the different methodologies used in these studies. The symmetrical strength of the GM muscle is reflective of the symmetrical nature of the legs during treading in water polo.

Shoulder functionality, as assessed by the KJOC questionnaire, was poor across the age groups with an average score of 82.5, and has not previously been reported for this cohort in the literature. This is below the recommendation of a score of above 90, established to be the norm in healthy baseball pitchers[349,350], but is higher than female swimmers[351]. In two studies on adolescent male water polo players, those with shoulder pain recorded far lower values (87.6 and 77.1), which fall below the abovementioned baseline KJOC scores, when compared to those without pain (93.1 and 91.3)[106,196], which may affect their throwing ability. Clinically, this suggests that our cohort has sub-optimal shoulder function, which may negatively impact TP and may be suggestive of increased risk of injury or an incomplete recovery from shoulder injury.

In summary, water polo players in this study exhibited the typical ERG but do not display a substantial GH IR ROM loss, and rather preserve this value to some extent. They exhibit strong scapular stabiliser scores and present with less asymmetry compared to other overhead athletes. This indicates that overhead athletes cannot be seen as a single entity displaying the same characteristics. This is important as it highlights that findings from a land-based pitching study cannot be extrapolated to a female adolescent water polo study. This is essential as it proposes that researchers, clinicians and coaches who work with sporting populations, need to evaluate their athletes continuously to identify areas of strengths and not implement intervention programmes prescribed for other sporting populations.

3.8.2 Predictors of throwing performance

Our cohort of female adolescent elite water polo players presented with slightly slower TS scores compared to that of other female water polo players between the ages of 18.9-24.9 years old[51,52,56,57,66,67,98,140] (Table 3.14). This is to be expected given the young age of this group (U14-U19), which is linked to training age (or number of water polo playing years) and their level of competition (current study was provincial level and comparative studies were national level)[52,56,66,67]. A high TS of 37.1 mph was recorded amongst a cohort of Olympic-level females, aged 24.9 years old[52]. This value is much higher than the average TS amongst our population of female adolescents, as well as amongst Spanish[98], Greek[67] and Australian[140] elite, water polo players, attributed to their Olympic level of competition and the training age. To the best of our knowledge, no previous study has investigated TS amongst such a young population of adolescent girls from U14, and thus comparative data is scarce.

However, compared to other females partaking land-based sports such as cricket[55] and handball[53,64,167,168], the female adolescents in the present study presented with much slower TS scores, which could be as a result of a heavier ball as well as different KC contributions in an aquatic-based environment.

Table 3.14: Summary of studies assessing TS amongst female water polo players

Study	Throwing speed (mph)	Population
Verwey et al., 2023	*23.7 mph*	*Adolescent (14-19yrs), elite players*
Stevens et al., 2010[51]	26.01 mph	Collegiate players. Aged 18.9 ± 1.04 years old
McCluskey et al., 2009[140]	34.23 mph	A-grade players. Aged 20.41 years old
Platanou and Varamenti, 2011[67]	34.76 mph	Players in Greek A league. Aged 21.7 years old (range 17-33).
Martinez et al., 2015[66]	Wing: 35.68 mph Centre: 36.13 mph	Elite wings and centres. Aged 21.6 (wings) – 22 (centres) years old
Alcaraz et al., 2011[98]	35.12 mph	Elite players from Spanish team. Aged 23.5 ± 2.1 years old
Freeston et al., 2014[52]	37.1 mph	Players in Australian Olympic team. Aged 24.9 years old
Varamenti and Platanou, 2008[298]	Seniors : 35.79± 1.34 mph Juniors: 33.78± 1.12 mph	Elite players from senior Greek national team (aged 26.3 ± 4.4 years) and junior Greek national team (aged 17 ± 1.2 years)
García-Cervantes et al., 2017[56]	31.05 mph	Elite players: European Championship in 2006 (Belgrade, Serbia) and World Championships in 2007 (Melbourne, Australia) – **no ages mentioned, just states players are 'of legal age'**
Panero et al., 2022[178]	Pre-training programme penalty shot: 29 mph. Post-training programme penalty shot: 28 mph.	Italian regional championship players - **No ages mentioned.**

TS scores increased linearly with age from U14 through to the U19 age group, establishing a trend of increasing speed with increasing age, mirroring the findings of another study[58]. This is anticipated, as isometric strength, which may contribute to increased ball speed, is shown to increase with age through adolescence, accelerating at around 15 years for girls[352]. Physical performance, encompassing strength (both static and explosive), endurance, speed, agility, flexibility and balance, is measured by the ability to perform a motor task, such as throwing. Most strength parameters measured in the present study (GH rotators, scapular stabilisers, GM) increased linearly with age, however, age group was the only variable found to be significantly correlated with TS in this study.

While other variables such as flexibility, scapular stabiliser strength and USR were correlated with TS, the multiple regression analysis (MRA) did not find these correlations to be statistically significant. Both dominant SA and UT strength were correlated with TS prior to the MRA, however, no specific strength variable was significantly correlated with increased TS, following the MRA. This is a surprising finding as strong GH internal rotators are needed for the generation of ball speed and this variable is often shown to predict TS in many different overhead sports[70,72,79–82], including water polo[67,78]. TS has previously been linked to GH internal rotator strength in other overhead sports such as water polo[67,78], cricket[79], handball[80] and tennis[70,72,81,82,84], however, this was not observed in the current study. GH internal rotator strength values were similar to other water polo players[106,196] and swimmers[344] but slightly lower than other overhead land-based athletes[35], which may be as a result of different KC contributions. The GHER:GHIR strength ratio was not correlated with TS or TA. Given that internal rotator strength is linked to TS in other sports[67,70,72,78–82,84], this finding may indicate a problem with this population of adolescent females in generating sufficient ball speed for optimal performance. Although a wide range in strength ratios amongst water polo players have been described in the literature[43], the optimal GHER:GHIR strength ratio for adolescent athletes has not yet been determined[196]. The relevance of this strength ratio to TP is unclear and there is minimal research exploring this phenomenon.

In overhead sport, throwing often occurs at an abduction angle of greater than 90 degrees[332] which would require improved scapular control and strength to control upward scapula rotation[28,127,128,199]. The strong scapular stabilisers of this population, would assist with increased USR at the end stages of GH elevation, as well as would also provide a strong platform and stable base from which the RC could operate, to produce GH IR torque for force generation and ultimate ball speed. This suggests that although strength may play a role in TS, the relationship between the musculoskeletal variables and TS may be a more complex and cumulative one with regards to predicting TS. It may also involve significant contributions from other muscles in the KC which were not evaluated in the present study. Therefore, age group, as a predictor of TS, likely represents multiple factors, of which strength is one. Other parameters such as technique and skill also improve with age[58], and would influence TS.

No previous study has investigated the relationship between TP in water polo players and HAS, provided by the GM muscle. While several land-based sports have found HAS to be predictive of TS[35,90], this was not the case in the present study. The fact that water polo is an aquatic-based sport and players throw from an unstable base, may influence the contribution of core, pelvic and leg strength to TS. This may be the case in the current study, especially in younger players who are possibly not able to get their bodies out of the water sufficiently. A strong gluteus maximus may be more relevant in water polo players as they attempt to propel themselves out of the water to shoot.

In the current study, non-dominant PML was also related to TS, prior to the MRA. A study has postulated that a decreased PML on the non-dominant side, may result in decreased thoracic rotation, negatively impacting the thrower's KC[102], resulting in poor performance. This thoracic rotation during the forward swing phase of the water polo throw is crucial to generating energy given the lack of ground reaction forces in water polo[116]. It may, therefore, be inferred that a normal length of the pectoralis minor muscle on the non-dominant side, may better facilitate rotation of the thorax. In contrast, a study on cricketers showed that greater thoracic ROM may not improve TS[75].

TA is multi-faceted and can be influenced by numerous phenomena. It requires both physical and mental proficiency. Skill acquisition and visuomotor[189] and cognitive control[161] contribute towards accuracy of throwing. While the importance of these components are acknowledged, this study aimed only to assess various musculoskeletal parameters and their influence on accuracy. This study found that dominant GH IR ROM was the greatest predictor of TA and showed a significant negative correlation with TA. Sitting height, dominant UT and SA strength were all found to be correlated with accuracy, prior to the MRA.

There are very few studies that have investigated TA within a population of water polo players[51,52,96,99,178,180,183] (Table 2.2), with none of them investigating adolescent females. A decrease in GH IR ROM associated with TA, is a novel finding and on the surface appears to create a potential conflict as a decrease in GH IR ROM has been associated with increased risk for injury amongst overhead athletes[11,24,41,106,186,276,278,291,323–328]. However, the mean GH IR ROM values for this group of female adolescents is above the average of other overhead athletes[39,40,102,108,126,166,195,210,213,219,220,223,228,251,252,255,262,270,278,323] and still fell within an acceptable range. This may indicate that a degree of capsular tightness may in fact provide stability to the GHJ, thereby enhancing TA, but this must be seen on a continuum where increased tightness may cause pain[40,208,210,332].

The TA scores in this cohort were low, with an average of only 2.3/8 targets being successfully hit, which translates to an accuracy score of 28.8%. This value is similar to other collegiate female water polo players (30%)[51] and handball players (22-31%)[168] of a similar age, but much lower than older females who represented their country in water polo[52]. This indicates that the level of competition, and number of playing years may positively influence TA, and thus TP. These findings are supported in a cohort of cricketers[55]. Our results showed that strength of the dominant SA and UT muscles were correlated with TA prior to the MRA. These strength values of these muscles had large standard deviations and so future studies with larger sample sizes could further investigate this relationship between scapular strength and TA.

Similarly to TS, TA scores in this study appear to increase linearly with age. This may be attributed to a greater number of water polo-playing years[99], resulting in the concomitant acquisition of skill. This is supported by a number of studies[55,99]. This linear increase was not reflected in the U16 age group who demonstrated a decrement in a number of the variables tested, revealing accuracy scores lower than the preceding age group (U15).

The general low accuracy scores of this group may be attributed to the accuracy test itself, which has not been validated. As previously discussed, comparison of TA scores is difficult as the methodologies differed vastly, with the reliability and validity of many methods not being well established. The distance from the participant to the target as well as the number of targets varied. Moreover, the number of attempts each participant had to hit the targets as well as the scoring systems, were inconsistent[55,59,96,99,178,180,183]. Testing TA with targets, rather than a goal space further limits comparison[52]. Also, evaluating accuracy without a mobile GK, may compromise the validity of the test. TA testing is complex, where other variables such as total error, which was found to be more reliable than hit percentage[52], may be more relevant.

3.8.3 Age group differences in MS variables

There were a number of age-related differences from the U14 to the U19 age group, which mostly followed a linear pattern of increasing values with increasing age. The U16 age group did not follow the normal trend of increasing scores with age and frequently demonstrated a decrement in a number of variables, compared to the preceding age group (U15). This may be due to the small sample size (n= 15) or simply that they were a weaker age group and not as competitive as the other age groups within the provincial set up. The linear increase in variables was clearly reflected in the remaining three age groups.

The key age-group finding in the present study was that the scapular stabiliser strength scores increased linearly from the U14 to the U19 age group. This linear increase in scapula stabiliser strength scores of the SA and UT muscles supports the observed increase in USR across age groups, as an increased USR would require superior strength of the scapular stabilising muscles, specifically SA and UT, to control this movement efficiently[353–355]. Better scapular stability leads to less impingement and thus better TS, as seen in the U19 age group.

The increased PML scores with increasing age may simply be a reflection of changes in body shape and size associated with growth. Habechian et al. (2018)[263] postulated that a strong SA muscle may resist the shortening of the pectoralis minor muscle, thereby preventing altered scapula positioning and reduced USR. The U19 age group had the strongest SA scores by almost 100N, which may further explain the observed increase of PML in this group. Further, a longer PML was observed in the non-throwing arm of this group, which also demonstrated increased levels of SA strength compared to the dominant side. This could also explain why as a whole, this side produced slightly stronger SA scores. Although this study, like many others[35], reported PML values, it is acknowledged that in the future, using the Pectoralis Minor Index (PMI)[7,106,196] may be more appropriate when evaluating age group trends. Alterations in PML can affect scapula kinematics[126,208], whereby an increased PML correlates with less anterior tipping of the scapula, leading to increased USR during elevation[268]. The advantages of increased USR in preventing shoulder pain has been well described[7,24,201,208,212 14,122,208,268]. A deficit in USR may also affect the proficiency of the KC[238] as a study has shown that during throwing, large forces produced by the lower limbs, influence wrist velocity[356]. Thus, a decreased USR may influence the transfer of these forces, resulting in a decrement in TP.

Adequate GH internal rotator strength is important in water polo for swimming, passing, shooting and defending effectively[196]. Volleyball players with higher skill levels demonstrated greater GH internal and external rotator strength scores compared to their less-experienced counterparts[357]. This finding is not reflected in the current study, as both the dominant GH internal and GH external rotator strength values were not statistically significant across the age groups. It is also important to note that GH internal rotator strength was the only variable to not change significantly throughout the age groups. This may be explained in part by the poor KJOC scores reported by the U19s. The lower scores may reflect a cumulative loading effect associated with the increase in the number of years playing water polo; a phenomena observed in swimmers[351]. Further, the low KJOC scores may indicate that they are either not fully recovered from a previous injury or are at risk of sustaining a shoulder injury[43,106,196]. Studies have found reduced GH internal rotator and external rotator strength to be the strongest predictor of shoulder injury[39]. The poor GH internal rotator strength documented in the U19s appears to be further reflected in the poor medicine ball throw test in this group, as scores were significantly lower compared to the two preceding age groups (U15 and U16).

The non-dominant GH external rotator strength scores appeared to be significantly different across the age groups from U14 to U19. A possible reason for this could be that the GH external rotators on the non-dominant side are repetitively used for defensive wrestling against opposition to protect the ball, and have therefore become stronger over time. This, in conjunction with the tripod stance that water polo players use when shooting[358], where the dominant leg held straight back, would lead to the non-dominant arm being stronger. This would provide a more stable position from which to shoot, thereby optimising ball speed and accuracy.

The KJOC scores were also found to be significantly different across the age groups. Question 3 of the KJOC questionnaire which assesses weakness (loss of strength/fatigue) that one experiences in their shoulder/elbow, had the lowest mean (7.48 ± 2.6). Olsen et al. (2006)[359] found that arm fatigue is strongly associated with injury in baseball. One quarter of the group tested positive to at least one of the impingement tests. While the implications of a single positive test on TP is not clear, it does appear that a large percentage of individuals with a positive test, had a low KJOC score. This could indicate poor functionality and lead to poor TP outcomes, in the form of reduced ball speed or accuracy. However, the implications of a low KJOC score on TP need to be studied longitudinally over time to establish a trend.

3.8.4 Limitations and future research recommendations

To the best of our knowledge, this is the largest female adolescent water polo study. While this sample size of 83 participants did provide statistical power, future studies could increase the sample size of the individual age groups.

100% of the study population were above their PHV, which portrays the homogeneity of the group, limiting the variability in MSK results due to biological age differences. While this strengthens the analysis for this group, care must be taken when extrapolating these findings to other population groups.

The use of the radar gun has been found to be reliable, but the accuracy test has not been validated. This may be valuable for this group of water polo players as they performed poorly across the age groups in this test, where the accuracy scores were fairly low. Scores were awarded for an accurate throw, even if the target was partially hit. Therefore, the scoring system used in this study may not have been sensitive enough to identify musculoskeletal variables which may influence TA, as the group performed consistently poorly. Moreover, both speed and accuracy testing were done without the presence of a GK, which may have influenced results.

Future studies could emulate game-conditions when assessing TS, as swim sprints have shown to decrease TS in female collegiate water polo players, as compared to control conditions[51].

Shoulder internal and external isometric strength testing was done at 90° of abduction. This may be seen as a limitation as the juniors (U14 and U15) may shoot from this position, however, the more senior players (U16 and U19) tend to shoot from a greater abduction angle[360]. Future studies could include testing from a more functional shooting position (GH abduction > 90°) as this is where muscles have adapted to perform with peak torque. However, Hams et al. (2019)[361] found that testing isometric strength in a neutral position and again at 90° of GH abduction, produced similar results. Eccentric testing, especially of the GH external rotators, can also be included as this may provide a greater understanding about the deceleration/follow-through phase, which forms a big component of TS, and ultimately, TP.

A more comprehensive assessment of other muscles contributing to the KC, such as other lower limb muscle groups should be undertaken in future studies. The inclusion of a more comprehensive KC strength assessment as suggested by Richardson et al. (2020)[362] can be considered to investigate a more significant correlation of cumulative strength of the KC, with TS and TA.

3.8.5 Conclusion

A typical female adolescent elite water polo player presents with an ERG, but preserves both GH IR ROM and TROM. They have a downwardly rotated scapula at rest but this increases throughout elevation. Unlike many overhead athletes the GHER:GHIR strength ratios are fairly symmetrical and they present with bilaterally strong scapular stabiliser strength scores. KJOC scores are below the recommended level indicating sub-optimal shoulder and elbow functionality. The musculoskeletal profile of an elite, female, adolescent water polo player varies across the age groups with significant differences noted from U14 to U19, for scapular muscle strength, USR, PML, non-dominant GH external rotator strength as well as medicine ball throws. The participants also presented with significant side-to-side asymmetries in GH IR and ER ROM and LT strength scores. This study adopted a rigorous statistical analysis procedure to reduce the risk of error during the MRA. Age group and dominant GH IR ROM were the only variables to significantly affect TS and TA, respectively. These findings may guide intervention programs aimed preventing injury and ultimately improving TP as participants move from one age group to the next.

CHAPTER 4: SUMMARY AND CONCLUSION

4.1 Summary

Water polo is a fast-growing, popular, and competitive water-based sport amongst adolescents. There is limited research on the musculoskeletal factors affecting TP in water polo, especially amongst a population of female adolescents. Understanding the musculoskeletal variables which predict TS and TA amongst female adolescent water polo players can inform interventions that can be implemented with an aim to improve TP in this group.

4.2 Main findings and clinical implications

1. The musculoskeletal profile of a female adolescent water polo player is different to that described for other overhead throwers. In addition, there appears to be variation in the musculoskeletal profiles within a sport itself. The typical 'throwers paradox' that is frequently described in the literature, may be typical of baseball pitchers, but is not a term that can be applied to all overhead throwing sports. **The implications for this are that generic throwing strengthening programs designed for baseball, should not just be followed without an adequate assessment of other throwing athletes, including water polo players.**

2. A rigorous process of data analysis was described. All four conditions (normality, linearity, no multi-collinearity and homoscedacity) had to be met to ensure eligibility of musculoskeletal variables correlated with throwing performance to be used in the multiple regression analysis. **This statistical approach can be used by other researchers to avoid the introduction of error during the data analysis process in studies investigating a large number of variables.**

3. While age group was the only factor significantly associated with TS, further analysis of the changes in musculoskeletal variables relative to age group revealed that a large number of variables showed improvement with increasing age. Variables such as bilateral PML, dominant UT and SA strength as well as USR at 90° (non-dominant) and 135° (dominant) of abduction were also associated with TS. Sitting height and dominant UT and SA strength were also associated with TA prior to the MRA. This indicates that age group may in fact represent several factors and again reinforces the complex nature of attempting to identify variables to predict certain outcomes like throwing performance. **The research implication for this is to include larger sample sizes per age group in an attempt to identify any other significant predictors of TS in water polo.**

4. Throwing accuracy was generally poor for this group of athletes. While it is not clear if this is a general finding in this cohort, or related to an accuracy test that is not validated, this study has highlighted a need for more research in this area. Water polo is a sport that is won largely by the number of goals scored. As a result, the accuracy of a shot is important. The only variable that significantly predicted a better TA, was a lower dominant GH IR ROM. Superficially, this would seem to conflict with a number of injury studies that have found a decreased dominant GH IR ROM to be predictive of injury. However, when seen in the context of the musculoskeletal profile of these athletes, it is evident that this group of athletes did not present with this component of the 'throwers paradox'. They do not exhibit reduced GH IR ROM scores, but rather preserved this ROM. **The implications of this finding for this cohort of throwing athletes would be that generic stretching, for example, the sleeper stretch, and doorway pectoral stretch[363] which is so easily prescribed to any overhead athlete, should rather be administered only when a deficit is identified. While these general stretching programs have proven to be beneficial amongst baseball pitchers, particularly for the posterior capsule, they should not be applied to all water polo players without a thorough individualised assessment as water polo players do not demonstrate the same substantial loss of GH IR ROM. Therefore, along with their ERG, stretching may cause further hypermobility, which can create an unstable shoulder and be detrimental to TP. Thus, health professionals and coaches can work together to draft interventions that are individualised and targets the specific needs of that athlete, to ensure optimal shoulder health and performance.**

5. GH internal rotator strength, which is frequently associated with increased TS in other sports, did not show the incremental increase in value with increasing age. This suggests a potential issue with the generation of ball speed in this population as optimal TS requires strong GH internal rotator strength amongst other variables. Further, this population demonstrated asymmetrical LT strength scores. **The clinical implication for this is the recommendation that athletes with weak GH rotators, strengthen these muscles accordingly as poor internal rotator strength is a strong predictor of shoulder injury[39]. The GH rotators should be strengthened symmetrically for an optimal GHER:GHIR strength ratio. The external rotators should be strengthened eccentrically as they play a significant role in deceleration after ball release. Concentric or isometric external rotator strengthening exercises are usually prescribed, which is ineffective to optimally load this muscle for its required functioning. Furthermore, it is suggested that these muscles, along with the scapular stabilisers, are strengthened simultaneously and in a functional position, so as to mimic the water polo position of throwing. This can be done at 90° of GH abduction as shown**

by Wilk et al. (2002)[41]. Strong scapular stabilisers (SA, UT and LT) are essential for adequate USR, as well as to provide a stable base from which the RC muscles can optimally function. Thus, having asymmetrical LT strength might have implications for shoulder injury as swimming is a bilateral sport, and these muscles should therefore be strengthened symmetrically. This can be done by performing the 'prone diagonals' exercise as described by Jameson et al. (2020)[106]. The SA muscles can be strengthened by performing the push up plus exercise described by Ludewig et al. (2004)[364]. Further the 'Y to T' exercise can be performed to improve overall scapular stability and control. This exercise is functional and mimics the positions adopted in swimming and water polo throwing[365]. These exercises may be implemented during pre-season and maintained throughout, for reduced injury risk and improved TP.

4.3 Other interesting findings and clinical implications

1. Pre-season testing is important to establish baseline scores with early identification of possible deficits and asymmetries, which can be addressed prior to the start of the season, thereby boosting performance and potentially reducing the risk of injury. **The importance of the KJOC assessment is noticed as it is cost-effective, easily administered, and allows for monitoring of players symptoms and functionality from a self-reported point of view. The musculoskeletal testing should comprise strength testing, ROM, flexibility and upward scapula rotation mobility should also be included.**

2. Although there are clear correlations between certain musculoskeletal variables and TP, the interplay between these variables may differ from individual to individual. Therefore, while TP is multifactorial with a number of variables playing a role, it is essential to remember that nothing works in isolation but rather depends on the optimal functioning of the KC together. **Thus, while identifying individual muscles is important, assessment and modification of segments as a whole should be included for holistic rehabilitation.**

In conclusion, this study provides a basis for further investigation into factors affecting TP in a population of female adolescent elite water polo players. Education of players as well as coaches and parents may prove to be beneficial as they better understand the musculoskeletal predictors of TP. Moreover, a pre-season screening is beneficial in order to identify those players with ROM or strength decrements and provide them with an early intervention so as to boost performance throughout the season.

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APPENDICES

Appendix A: Summary of studies assessing TS in overhead sports for both genders

Study	Throwing Speed (mph)	Population
Water polo		
García-Cervantes et al., 2017[56]	Males = 37.89 mph	Elite players: European Championship in 2006 (Belgrade, Serbia) and World Championships in 2007 (Melbourne, Australia) – **no ages mentioned, just 'of legal age'**
De Siati et al., 2015[58]	13-15yrs: 26.64 mph 16-18yrs: 30.65 mph	Males (13-15yrs) and (16-18yrs)
Zinner et al., 2015[89]	42.58mph	16 year old males
Marques et al., 2012[20]	Pre: 32.79-32.91 mph Post: 33.64-33.69 mph	17 year old males
Royal et al., 2006[180]	49.7 mph	Males: junior elite players at Australian Institute of Sport. Aged 17.2 years.
Van Der Wende, 2005[183]	40.71 mph	Males at a national level. Aged 20.8 ± 2.3 years old
McKenzie et al., 2020[94]	31.3 – 48 mph	Males in 1st division league. Aged 21 years old
Melchiorri et al., 2014[68]	Sub-elite: 41.2 mph Elite: 51mph	Males - Sub-elite (20.2 years) and elite (23.3 years)
Idrizovic et al., 2014[91]	46.6 mph	Males. Members of national team and club competing in Adriatic League Competition. Aged 23 years old
Ferragut et al., 2011[61]	45.91 mph	Males part of Spanish national team. Aged 24 ± 5.1 years old
Ferragut et al., 2015[62]	47.2 mph	Males playing at Spanish King's Cup. Aged 24.6 ± 5.1 years old
Botonis et al., 2015[96]	43 mph	Males in 1st division. Aged 28 ± 5 years old (range 19-35)
Baseball		
Keeley et al., 2014[184]	40.5 mph	Youth pitchers, aged 11.5 ± 3.1 years old
Sgroi et al., 2015[69]	64 ± 10 mph	Aged 14.7 years old
Reinold et al., 2018[73]	**No value given**	Aged 15.3 ± 1.2 years old (range 13-18)
Keller et al., 2015[164]	71.9 mph	High school pitchers. Aged 16.9 ± 0.9 years old (range 15-18)
Kawamura et al., 2017[299]	High school: 77.2 mph Professionals: 80 mph	High school (aged 17 years) and professional pitchers (Aged 26.2 ± 2.7 years old).
Freeston, Adams, Rooney, 2015[95]	73.81 mph	Males, representing Wales. Aged 19.6 ± 2.6 years old
Marsh et al., 2018[166]	**No value given**	Collegiate and professionals. Aged 19.9 ± 1.3 years old (range 13-18)
Yanagisawa and Tanigichi, 2018[90]	± 80 mph	Collegiate male pitchers. Aged 19.9 ± 0.7 years old
Ueda et al., 2021[322]	69.3 mph	Baseballers playing at University/for an Independent League. Aged 20 ± 1 years old
Werner et al., 2008[74]	79 ± 7 mph	College level pitchers. Aged 20 ± 2 years old
Cricket		
Freeston et al., 2016[79]	68.2 mph	Males. Aged 21.1 years old
Talukdar et al., 2015[75]	Standing: 69.6 mph Sitting: 53.8 mph	Male, professionals. Aged 23.8 years old

Ahmed et al., 2020[35]	61.45 mph 77.2 mph (professional) 75.7 mph (high school)	Males. Amateur (23 ± 4 years old) and elite (23.9 ± 5.1 years old)
Freeston, Ferdinands, Rooney, 2007[55]	Elite senior males: 68 mph Elite U19 junior males: 62.4mph Elite U17 junior males: 62.2mph Sub-Elite senior males: 60.6mph Elite senior females: 52.1mph Elite U19 junior females: 43.2mph	Elite senior males (aged 24.4 ± 3.4 years old) Elite U19 junior males (aged 17.6 ± 0.6 years old) Elite U17 junior males (aged 15.8 ± 0.4 years old) Sub-Elite senior males (aged 23.7 ± 2.8 years old) Elite senior females (aged 24 ± 2.6 years old) Elite U19 junior females (aged 17.4 ± 0.8 years old)
Handball		
Genevois et al., 2014[167]	38.89 mph with D arm.	Females (elite) at high school. Aged 15.8 ± 0.8 years old
Mascarin et al., 2017[53]	30.4 – 33.1 mph	Females. Aged 15.3 ± 0.9 years old
Saavedra et al., 2018[64]	U15 – 42.5 mph U17 – 42.13 mph U19 – 45.67 mph A team – 46.48 mph	Females, aged 18.2 ± 4 years old belonging to the Icelandic national teams at U15 (aged 14.5 ± 0.5 years old), U17 (aged 16.1 ± 0.6 years old), U19 (aged 18.3 ± 0.7 years old) and A (aged 23.7 ± 3.9 years old) team level
Zapartidis et al., 2007[168]	36.2 – 37.8 mph	Females, aged 20.5 ± 1.9 years old. Playing in Greek 1st division at National championships
Pontaga and Ziddens , 2014[80]	47 mph	Male, elite adolescents. Aged 14.6 ± 0.8 years
Debanne and Laffaye, 2011[63]	48.5 mph	Males, aged 21.1 ± 3 years old (range 19-24) competing in French championship (3rd, 6th and 9th divisions)

Appendix B: Summary of risk factors for shoulder pain/injury

	Scapula Positioning	Flexibility	ROM	Muscle Strength	Other
Baseball pitchers	- Scapula dyskinesis: **contradictory** - Shown to both be predictive[201,322] as well as not predictive[366] of injury	- Posterior shoulder/capsule tightness leading to scapula dyskinesis[367]	- GIRD: **contradictory**. - GIRD shown to be a risk factor[324,325] and not to be an independent risk factor[23,258,368–370] injury. - GIRD side-to-side IR difference of > 25° = increased injury risk[186,324] - Adolescents with side-to-side IR difference of > 13° = increased injury risk[324] - Decreased dominant GH IR ROM[186,326] = increased injury risk - GH ER ROM: **contradictory** - Decreased GH ER on dominant side is both a risk factor[223] and not an independent risk factor[23,258,324,325,368,371] - Decreased GH ER ROM = increased risk UCL tears[369] - Increased GH ER ROM > 130° = radiographic abnormalities of elbow[216] - TROM: **contradictory** - Decreased TROM is both an independent risk factor for injury [186,369] and not an independent risk factor for injury[23,258,324,325,368] - TROM difference >5 = increased risk of injury[223] TROM deficits are associated with GIRD[202]	- Decreased GH external rotator strength[204,312] - Decreased middle trap and supraspinatus strength[258] - Increased GH internal rotator strength on dominant vs non-dominant[258] - Preseason decreased GH external rotator strength[204] - Preseason decreased supraspinatus strength[23] - Deficits in GH internal and external rotator strength are associated with GIRD[202]	- Increasing age[216,217] - Increasing pitches per game[217,372] - > 80 pitches per game = 3.8X increased risk for elbow or shoulder surgery[359] - TS > 85mph = 2.5X increased risk for elbow or shoulder surgery[359] - Arm fatigue[373]
Water polo players	- Scapula dyskinesis (2° to changes in PML)[208].	- Decreased PML on dominant side (also	- Significant side-to-side asymmetries in GH IR and ER[40] ROM[106].	- Decreased shoulder rotator strength[39,361]. - Decreased ER strength (relative to IR)[39]. - Imbalance between ER and IR[18,43,106].	- Deficits in proprioception[43].

		causing scapula dyskinesis)[7,201,208]. - Posterior capsule tightness (secondary to alterations in PML)[208].	- Significant difference of dominant vs non-dominant TROM[40]. - GIRD > ERG = pathological[11]. - TROM difference ≥ 7.5 = 3.6X increased risk of shoulder pain/injury[39].	- GH external rotator strength corrected for BW (≤12.5% of body weight) and GH IR strength (≤ 16.8% of BW) is linked with an increased risk of shoulder pain/injury[24].	
Swimmers	- Scapula dyskinesis[374].	- Decreased PML[24,212]. - Joint laxity[22].	- Increased (>100) or decreased (<93) GH ER ROM[22,375]. - Decreased GH flexion ROM[24].	- Weak SA[376,377] - Increased GHER:GHIR strength ratio from preseason to postseason[344] - Increased GH external rotator strength from preseason to postseason[344] - Decreased middle trapezius strength[24] - Decreased GH internal rotator strength[24] - Significantly longer muscle latency times of middle and lower trapezius for injured vs non-injured[30]	- Previous pain/injury history[22,378] - Increasing competitive level[22,379] - Gender: Females at 3X increased risk[212] - Acute:Chronic workload ratio[379] - Hand entry position[379]
Cricketers	- Altered scapula positioning[198]	- Decreased non-dominant PML[102]	- GH rotational ROM[380] - Insufficient dominant GH ER (<5 greater than non-dominant) = 2.2X ↑ risk of shoulder pain/injury[223]	- Decreased GH external rotator strength[102] - Decreased GHER:GHIR strength ratio[102]	- Supraspinatus tendon thickness of > 5.85mm[102]
Tennis players	- Increased USR on dominant side[7] - Scapula dyskinesis[7]	- Decreased PML[7]	- Decreased GH IR ROM[276,327] - GIRD[323] - Increased GH ER ROM[323] - Decreased TROM[323]	- Imbalances between dominant and non-dominant SA and UT strength[7]	- Volume of tennis[327,381] - Poor technique[382] - Racquet properties[328]

Handball players	- Scapula dyskinesis[18,201,278]	- Posterior shoulder stiffness on dominant side[383]	- ER > 7.5° and GIRD > 7.5°[328] - < 5° gain in ER ROM (retraction of IR)[201] - Decreased TROM[201] - Increased ERG and GIRD = risk factors for girls only[278] - Increased GH IR ROM[215] - GIRD > 10° leads to decreased TROM and posterosuperior impingement in 75% of players[291]	- Decreased GH external rotator strength[18,201,278,282] contradicted by Vigolvino et al. (2019)[383] who showed increased external rotator strength on dominant side. - Females with low concentric GHER:GHIR strength ratio and high eccentric internal rotator to concentric external rotator strength ratio = 2.5X increased risk of overuse and acute injury[282]	- Previous injury[278,384–386] - Workload[384] - Fatigue[387] - Female sex[213–215]

**The above reported sports are not all existing overhead sports, however, they do have the largest amount of research investigating these parameters*

Appendix C: Ethical approval

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room G50- Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: hrec-enquiries@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

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28 September 2021

HREC REF: 576/2021

Dr J Gray
Division of Physiological Sciences
Human Biology
Email: janine@thelockerroom.org.za
Student: VRWLIA001@myuct.ac.za

Dear Dr Gray

PROJECT TITLE: THE INFLUENCE OF INTRINSIC RISK FACTORS ON SHOULDER PAIN AND THROWING PERFORMANCE AMONGST ADOLESCENT, PROVINCIAL WATER POLO PLAYERS, IN SOUTH AFRICA-MSC CANDIDATE-MS LIANNE VERWEY-SUB-STUDY LINKED TO 405/2019

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020: 06 July 2020 & 01 July 2021.

Approval is granted for one year until the 30 September 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Ms Lianne Verwey will also be involved in this study.

Please quote the HREC REF 576/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

Signed by candidate

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use: Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI), and Declaration of Helsinki (2013) guidelines. The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

Appendix D: Ethical approval renewal

HUMAN RESEARCH
ETHICS COMMITTEE
31 JUL 2023
HEALTH SCIENCES FACULTY
UNIVERSITY OF CAPE TOWN

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

FHS016: Annual Progress Report / Renewal

HREC office use only (FWA00001637; IRB00001938) **This serves as notification of annual approval, including any documentation described below.**			
☑ Approved	Annual progress report	Approved until/next renewal date	30.7.2024
☐ Not approved	See attached comments		
Signature Chairperson of the HREC/ Designee	Signed by candidate	Date Signed	31/7/2023

Note: Please email this form and supporting documents (if applicable) in a combined pdf-file to hrec-enquiries@uct.ac.za.
Please clarify your plan for research-related activities during COVID-19 lockdown.
Please use the latest form found on our website: http://www.health.uct.ac.za/fhs/research/humanethics/forms

Comments to PI from the HREC
Thank you for the clarifying documents

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	18/07/2023		
HREC REF Number	576/2021	Current Ethics Approval was granted until	30 September 2022
Protocol title	The influence of intrinsic risk factors on shoulder pain and throwing performance amongst adolescent, provincial water polo players, in South Africa.		
Protocol number (if applicable)	N/A		
Are there any sub-studies linked to this study?	☐ Yes	X No	
If yes, could you please provide the HREC Reference number for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study.			
Principal Investigator	Dr Janine Gray		
Department / Office Internal Mail Address	janine@thelockerroom.co.za		

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

Appendix E: Informed consent form (participant)

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD
HEALTH SCIENCES

DHRS
Department of Health and Rehabilitation Sciences
FACULTY OF HEALTH SCIENCES

Divisions of Communication Sciences & Disorders • Disability Studies • Nursing & Midwifery • Occupational Therapy • Physiotherapy

F45 Old Main Building, Groote Schuur Hospital
Observatory, Cape Town, South Africa, 7925
Telephone: +27 (0) 21 406 6401
Website: www.dhrs.uct.ac.za

Dear participant

I am a master's student at University of Cape Town's Division of Physiotherapy. I am performing a study to identify risk factors that pre-dispose athletes to developing shoulder pain and whether these factors affect throwing performance, or not. All of the information obtained from this study will be used towards completing the research component of my MSc Exercise and Sports Physiotherapy degree. The Human Research Ethics Committee, at the Faculty of Health Sciences from University of Cape Town has ethically approved this study.

In order for you to take part in this study, you will need to provide informed consent by reading and signing this form. Please ensure you thoroughly read through this document and ask about anything that is unclear before you sign.

Why is this study being conducted?

It is known that there is a high risk for shoulder injuries amongst adolescent water polo players. This is due to repetitive swimming and overhead throwing in extreme shoulder ranges. This study aims to identify the risk factors that predispose an athlete to the development of shoulder pain and whether this affects their throwing performance. If these risk factors can be successfully identified through a pre-season screening battery of tests, aimed at assessing range of motion, muscle strength etc, an injury prevention programme can be implemented, with the aim of reducing the injury rates amongst players while simultaneously maintaining or enhancing throwing performance.

Why are you being asked to participate in this study?

You are asked to participate in the study because you have been selected to represent WP water polo and are between the ages of 14 and 19. Adolescents are included in the study because they are at a high risk for developing a shoulder injury.

How many people will participate in this study?

A minimum of sixty athletes will take part in this study.

How long will the study be conducted for?

Data will be gathered from the players after selection. They will be monitored remotely for the preparation phase until the end of the Nationals tournament in December 2021.

Will you receive payment for taking part in the study?

No, you will not be paid to participate in this study.

How do we determine if you are eligible to participate in this study?

You are eligible to participate in this study if you meet the following criteria:

- Selected for Western Province Water polo A or B sides (or one of the non-travelling reserves), in the U14, 15, 16 or 19 age-groups.

When will testing be done and how long will it take?

Testing will be performed over a weekend (Friday, Saturday and Sunday) in October 2021, once Western Province teams have been finalized and selected. A date will be communicated as soon as we have confirmation.

Where will testing take place?

Testing will take place in two sessions in October. The musculoskeletal tests will be performed at an indoor facility and the throwing performance tests will be performed during a pool session on a separate day. A date will be communicated as soon as we have confirmation.

What happens if you decide to take part in this study?

You will be asked to participate in a screening session. This will happen before the pre-season starts. Your choice to participate in the study is completely voluntary and will be always kept confidential (i.e., the coaches will not be aware of your decision) and will not jeopardize your position in the team at all.

You will also be asked to complete a questionnaire regarding your shoulder and ability to carry out activities of daily living as well as sporting activities. You will also participate in a physical assessment whereby measurements in the form of mass, standing height and seated height will be recorded as well as a series of physical tests (range of motion, strength, flexibility). Lastly, you will participate in throwing performance testing whereby throwing speed and accuracy will be assessed using a standard-sized water polo ball in the swimming pool. You will be made aware of the above procedures and testing methods prior to the start of the study and will also be given an opportunity to warm-up prior to some of the tests. Once the initial testing has been completed, injury monitoring will be done over the interceding weeks prior to and during Nationals, whereby you will be required to fill in a short online survey (with a maximum of 6 questions), every week, regarding their shoulder pain and training load. Any concerns regarding the above process will be appropriately addressed.

The testing protocol that will be followed, is described below. Qualified clinicians will conduct all the tests. You will be asked to please wear shorts and a t-shirt throughout the screening process but will need a costume for the throwing performance testing in the swimming pool.

1. **Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score**

   This is a questionnaire that assesses overall functionality and sporting performance, upper limb symptoms and interpersonal relationships and performance. There are three sections and a total of 19 questions. You will be asked to fill it in prior to the start of the study and again at the end of the study. It takes approximately 5 minutes to fill in.

2. **Anthropometric Data**
   a. **Body Mass**
   This will be measured with you standing barefoot and, in your shorts, and t-shirt on a calibrated scale.
   b. **Height**
   This will be measured firstly in standing, with you barefoot, heels against the wall, and, in your shorts, and t-shirt. Secondly, height will be measured in sitting, on a chair, 50cm above the ground and with your heels flat on the floor and back flat against the wall.
   c. **Maturation Assessment**
   The body mass, height and leg length measurements will be used to predict your fastest growth spurt and how close you are to that point.

3. **Shoulder Specific Tests**

The following tests will then be done on both your shoulders, taking approximately 25 minutes to complete.

   a. **Pain Provocation Tests (used to test for the presence of shoulder pain by a yes/no answer):**
      i. Hawkin's-Kennedy Test
      ii. Jobe's Test/Empty Can
      iii. Full Can
   b. **Pectoralis minor muscle (deep chest muscle) length**
   c. **Shoulder joint rotation range of motion**
   d. **Shoulder blade rotational range of motion**
   e. **Muscle strength of shoulder rotator muscles**
      i. Internal (inward) rotators
      ii. External (outward) rotators
   f. **Muscle strength of the hip stabilisers**
      i. Gluteus Medius
   g. **Muscle strength of the shoulder blade stabilisers**
      i. Serratus Anterior muscle
      ii. Upper Trapezius muscle
      iii. Lower trapezius muscle
   h. **Medicine Ball power throws**

4. **Throwing performance testing**

Throwing speed and throwing accuracy will be tested in the pool, aiming at goals using a standard-sized water polo ball.

5. **Injury Monitoring**

Throughout the duration of the water polo season until Nationals, you will be required to fill out a quick questionnaire of your perceived shoulder pain, fatigue and strength as well as training load. This will be done weekly on a shared google document and will take approximately 1 minute to fill in. The first will be about training load, the second about shoulder pain and the third about shoulder strength.

For this study, shoulder pain is defined as the onset/presentation of pain characterized by a physical complaint for a period of a day or longer, that presents itself during training or a match, regardless of whether medical intervention is required or if you miss out on training or match time due to the pain. However, you will be required to document any time missed from training or a match, due to their pain and whether further medical intervention was required. Shoulder strength will be defined as the shoulder feeling tired or weak, limiting performance or the ability to perform an activity.

What are the potential risks associated with this study?

There are minimal to no risks to participating in this study, however a few potential small risks include:

- A short-lived period of shoulder pain caused by the screening and throwing testing. This should go away after a few minutes, but pain severity will be monitored throughout the process. However, if the pain does not settle, or increases, the testing procedure will be stopped immediately.
- For 48-72 hours after the testing, you might experience muscle soreness in your shoulders and surrounding areas. This is not uncommon as many athletes experience this after performing physical movements that they are not used to.

What are the benefits associated with participating in this study?

All the results obtained from testing will be issued to you for your own interest. You can use the results to identify potential risks for shoulder pain and/or injury to better understand your shoulder's capacity and 'health' and potential areas to improve performance. Should you experience shoulder pain or sustain an injury during testing, you will be appropriately referred to a health care practitioner. We anticipate that the study findings will ultimately provide assistance in decreasing the number of injuries to the shoulder experienced by adolescent water polo players. This can be done by educating coaches on the possible risk factors associated with shoulder pain development and helping them to design preventative programs with the goal of addressing the risk factors for shoulder pain.

It is important to note that UCT offers a no-fault insurance that will cover all participants if something goes wrong. Any trial-related injury corresponding to the British Pharmaceutical industry (ABPI) guidelines (1991) will be covered by the insurance with quick payment of compensation. These standards recommend that UCT, without any legal obligation, should compensate participants without the need of them proving that UCT is at fault. An injury caused by the study activities is considered trial related. Any injuries sustained during the trial, whether it is research-related, or a related complication should be made known to the study investigators immediately. UCT has the right to withhold compensation if, and to the extent that, the injury sustained was due to the participant's lack of following the instructions as explained while taking part in the study. The participant's right to claim compensation for injury where negligence is proved is not affected. Injury sustained during the water polo season is not covered by this insurance.

Please note that no physiotherapy treatment will be given to participant's if they do sustain an injury during the study. We will give advice and refer to relevant medical professional where appropriate.

What happens if you decide not to take part in this study?

Your decision to take part in this study is voluntary. You will be able to withdraw from the study at any point, without any consequences. Your decision will be kept confidential, will not be known to the Western Province coaches, and will not impact on any selection criteria.

Who to contact if you have any queries or concerns related to this study?

Please feel free to contact me, the student researcher, or my supervisor, Dr Janine Gray if you would like to know more or are unsure of anything related to the study. All queries will be kept confidential.

Student researcher: Lianne Verwey
Cell number: 082 320 0090
Email: lianneverwey@gmail.com

Research supervisors:

Dr Janine Gray
Cell number: O82 4983178
Email: janine@thelockerroom.org.za

Prof Steve Roche
Cell number: 0837275454
Email: Stephen.roche@uct.ac.za

Please feel free to contact Prof Blockman if you have any ethical uncertainties or questions relating to your child's rights and welfare as someone taking part in this research study.

Tel number: 021 406 6338

Participant consent form

The influence of intrinsic risk factors on shoulder pain and throwing performance amongst adolescent, provincial water polo players, in South Africa.

I, ________________________________, have been entirely informed about inclusion in this study ('The influence of intrinsic risk factors on shoulder pain and throwing performance amongst adolescent, provincial water polo players, in South Africa')

<u>Using an 'X', please indicate, which components of this study you are consenting to participate in:</u>

☐ I consent to my participation in the shoulder musculoskeletal screening and throwing performance testing to be conducted by UCT researchers and for me to fill-out an online survey every two weeks for three months to monitor for any shoulder pain and/or injuries throughout the season. I understand that I will perform a number of tests as mentioned above. I acknowledge that the testing procedure will be conducted at a designated venue in Cape Town in October 2021.

☐ I consent to my shoulder musculoskeletal screening information to be shared within this UCT research team to allow for analysis as described above.

I have fully read and understand the participant information sheet and have had the chance to ask questions relating to the procedures and outcomes of the tests used in this study.

I acknowledge that any information gathered throughout this study will be kept confidential; will only be used for purpose of scientific research; and that my personal information will not be made publicly available under any circumstances.

The potential risks and benefits associated with my participation in this study have been thoroughly explained to me.

I understand that I may choose to withdraw from the study at any point, without any consequences. Finally, I consent to take part in this study.

______________________	______________________	________
Full Name (please print)	Signature of Participant	Date
	______________________	________
Lianne Verwey	Signature of Student Researcher	Date
	______________________	________
Dr Janine Gray	Signature of Research Supervisor	Date

Appendix F: Informed consent form (parent/legal guardian)

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD
HEALTH SCIENCES

DHRS
Department of Health and Rehabilitation Sciences
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Divisions of Communication Sciences & Disorders • Disability Studies • Nursing & Midwifery • Occupational Therapy • Physiotherapy

F45 Old Main Building, Groote Schuur Hospital
Observatory, Cape Town, South Africa, 7925
Telephone: +27 (0) 21 406 6401
Website: www.dhrs.uct.ac.za

Dear parent/legal guardian

I am a master's student at the University of Cape Town's Division of Physiotherapy. I am performing a study to identify risk factors that pre-dispose athletes to developing shoulder pain and whether these factors affect throwing performance, or not. All of the information obtained from this study will be used towards completing the research component of my MSc Exercise and Sports Physiotherapy degree. The Human Research Ethics Committee, at the Faculty of Health Sciences from University of Cape Town has ethically approved this study.

In order for your child to take part in this study, you as the parent/legal guardian will need to provide informed consent by reading and signing this form. Please ensure you thoroughly read through this document and ask about anything that is unclear before you sign.

<u>Why is this study being conducted?</u>
It is known that there is a high risk for shoulder injuries amongst adolescent water polo players. This is due to repetitive swimming and overhead throwing in extreme shoulder ranges. This study aims to identify the risk factors that predispose an athlete to the development of shoulder pain and whether this affects their throwing performance. If these risk factors can be successfully identified through a pre-season screening battery of tests, aimed at assessing range of motion, muscle strength etc, an injury prevention programme can be implemented, with the aim of reducing the injury rates amongst players while simultaneously maintaining or enhancing throwing performance.

<u>Why is your child being asked to participate in this study?</u>
Your child is asked to participate in the study because they have been selected to represent WP and are between the ages of 14 and 19. Adolescents are included in the study as they are at a high risk for developing a shoulder injury.

<u>How many people will participate in this study?</u>
A minimum of sixty athletes will take part in this study.

<u>How long will the study be conducted for?</u>
Data will be gathered from the players after selection. They will be monitored remotely for the preparation phase until the end of the National tournament in December 2021.

<u>Will my child receive payment for taking part in the study?</u>
No, they will not be paid to participate in this study.

How do we determine if your child is eligible to participate in this study?
Your child is eligible to participate in this study if they meet the following criteria:
Selected for Western Province water polo A or B sides (or one of the non-travelling reserves), in the U14, 15, 16 or 19 age-groups.

When will testing be done and how long will it take?
Testing will take place in two sessions in October. The musculoskeletal tests will be performed at an indoor facility and the throwing performance tests will be performed during a pool session on a separate day. A date will be communicated as soon as we have confirmation.

Where will testing take place?
The screening component of the study will take place in an indoor venue in Cape Town. The throwing performance testing will be done in an outdoor swimming pool in Cape Town.

What happens if you decide to allow for your child to take part in this study?
Your child will be asked to participate in a screening session that will be approximately 2 hours long. This will happen before the pre-season starts. Your child's choice to participate in the study is completely voluntary and will be always kept confidential (i.e., the coaches will not be aware of their decision) and will not jeopardize their position in the team at all.

Your child will also be asked to complete a questionnaire regarding his shoulder and ability to carry out activities of daily living as well as sporting activities. Your child will also participate in a physical assessment whereby measurements in the form of mass, standing height and seated height will be recorded as well as a series of physical tests (range of motion, strength, flexibility). Lastly, your child will participate in throwing performance testing whereby throwing speed and accuracy will be assessed using a standard-sized water polo ball in the swimming pool. Your child will be made aware of the above procedures and testing methods prior to the start of the study and will also be given an opportunity to warm-up prior to some of the tests. Once the initial testing has been completed, injury monitoring will be done over the interceding weeks prior to and during Nationals, whereby your child will be required to fill in a short online survey (with a maximum of 6 questions), every week, regarding their shoulder pain and training load. Any concerns regarding the above process will be appropriately addressed.

The testing protocol that will be followed, is described below. Qualified clinicians will conduct all the tests. Your child will be asked to please wear shorts and a t-shirt throughout the screening process but will need a costume for the throwing performance testing in the swimming pool.

1. **Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score**

   This is a questionnaire that assesses overall functionality and sporting performance, upper limb symptoms and interpersonal relationships and performance. There are three sections and a total of 19 questions. Your child will be asked to fill it in prior to the start of the study and again at the end of the study. It takes approximately 5 minutes to fill in.

2. **Anthropometric Data**
   a. **Body Mass**
      This will be measured with your child standing barefoot and, in their shorts, and t-shirt on a calibrated scale.
   b. **Height**
      This will be measured firstly in standing, with your child barefoot, heels against the wall, and, in their shorts, and t-shirt. Secondly, height will be measured in sitting, with your child on a chair, 50cm above the ground and with their heels flat on the floor and back flat against the wall.
   c. **Maturation Assessment**
      The body mass, height and leg length measurements will be used to predict your child's fastest growth spurt and how close they are to that point.

3. **Shoulder Specific Tests**
   The following tests will then be done on both your child's shoulders, taking approximately 25 minutes to complete.
   a. **Pain Provocation Tests (used to test for the presence of shoulder pain by a yes/no answer):**
      i. Hawkin's-Kennedy Test
      ii. Jobe's Test/Empty Can
      iii. Full Can
   b. **Pectoralis minor muscle (deep chest muscle) length**
   c. **Shoulder joint rotation range of motion**
   d. **Shoulder blade rotational range of motion**
   e. **Muscle strength of shoulder rotator muscles**
      i. Internal (inward) rotators
      ii. External (outward) rotators
   f. **Muscle strength of the hip stabilisers**
      i. Gluteus Medius
   g. **Muscle strength of the shoulder blade stabilisers**
      i. Serratus Anterior muscle
      ii. Upper Trapezius muscle
      iii. Lower trapezius muscle
   h. **Medicine Ball power throws**

4. **Throwing performance testing**
   Throwing speed and throwing accuracy will be tested in the pool, aiming at goals using a standard-sized water polo ball.

5. **Injury Monitoring**
   Throughout the duration of the water polo season until Nationals, your child will be required to fill out a quick questionnaire of their perceived shoulder pain, fatigue and strength as well as

training load. This will be done weekly on a shared google document and will take approximately 1 minute to fill in. The first will be about training load, the second about shoulder pain and the third about shoulder strength. For this study, shoulder pain is defined as the onset/presentation of pain characterized by a physical complaint for a period of a day or longer, that presents itself during training or a match, regardless of whether medical intervention is required or if your child misses out on training or match time due to the pain. However, your child will be required to document any time missed from training or a match, due to their pain and whether further medical intervention was required. Shoulder strength will be defined as the shoulder feeling tired or weak, limiting performance or the ability to perform an activity.

<u>What are the potential risks associated with this study?</u>

There are minimal to no risks to participating in this study, however a few potential small risks include:

- A short-lived period of shoulder pain caused by the screening and throwing testing. This should go away after a few minutes, but pain severity will be monitored throughout the process. However, if the pain does not settle, or increases, the testing procedure will be stopped immediately.
- For 48-72 hours after the testing, your child might complain of muscle soreness in their shoulders and surrounding areas. This is not uncommon as many athletes experience this after performing physical movements that they are not used to.

<u>What are the benefits associated with participating in this study?</u>

All the results obtained from testing will be issued to your child for their own interest. Your child can use the results to identify their potential risks for shoulder pain and/or injury to better understand their shoulder's capacity and 'health' and potential areas to improve performance. Should you child experience shoulder pain or sustain an injury during testing, they will be appropriately referred to a health care practitioner. We anticipate that the study findings will ultimately provide assistance in decreasing the number of injuries to the shoulder experienced by adolescent water polo players. This can be done by educating coaches on the possible risk factors associated with shoulder pain development and helping them to design preventative programs with the goal of addressing the risk factors for shoulder pain.

It is important to note that UCT offers a no-fault insurance that will cover all participants if something goes wrong. Any trial-related injury corresponding to the British Pharmaceutical industry (ABPI) guidelines (1991) will be covered by the insurance with quick payment of compensation. These standards recommend that UCT, without any legal obligation, should compensate you without the need of you proving that UCT is at fault. An injury caused by the study activities is considered trial related. Any injuries sustained during the trial, whether it is research-related, or a related complication should be made known to the study investigators immediately. UCT has the right to withhold compensation if, and to the extent that, the injury you sustained was due to your lack of following the instructions as explained while taking part in the study. Your right to claim compensation for injury where negligence is proved is not affected. Injury sustained during the water polo season is not covered by this insurance.

Please note that no physiotherapy treatment will be given to your child if they do sustain an injury during the study. We will give advice and refer to relevant medical professional where appropriate.

<u>What happens if you decide not to allow your child to take part in this study?</u>

Your decision to allow your child to take part in this study is voluntary. You and your child will be able to withdraw from the study at any point, without any consequences. Your decision will be kept confidential, will not be known to the Western Province coaches, and will not impact on any selection criteria.

<u>Who to contact if you have any queries or concerns related to this study?</u>

Please feel free to contact me, the student researcher, or my supervisors, Dr Janine Gray or Prof Steve Roche if you would like to know more or are unsure of anything related to the study. All queries will be kept confidential.

Student researcher: Lianne Verwey
Cell number: 082 320 0090
Email: lianneverwey@gmail.com

Research supervisors:

Dr Janine Gray
Cell number: O82 4983178
Email: janine@thelockerroom.org.za

Prof Steve Roche
Cell number: 0837275454
Email: Stephen.roche@uct.ac.za

Please feel free to contact Prof Blockman if you have any ethical uncertainties or questions relating to your child's rights and welfare as someone taking part in this research study.

Tel number: 021 406 6338

Participant's parent/legal guardian consent form

The influence of intrinsic risk factors on shoulder pain and throwing performance amongst adolescent, provincial water polo players, in South Africa

I, ________________________________, have been entirely informed about the inclusion of my child in this study ('The influence of intrinsic risk factors on shoulder pain and throwing performance amongst adolescent, provincial water polo players, in South Africa')

Using an 'X', please indicate, which components of this study you are consenting to allow your child to participate in:

☐ I consent to my child's participation in the shoulder musculoskeletal screening and throwing performance testing to be conducted by UCT researchers and for my child to fill-out an online survey every two weeks for three months to monitor for any shoulder pain and/or injuries throughout the season. I understand that my child will perform a number of tests as mentioned above. I acknowledge that the testing procedure will be conducted at a designated venue in Cape Town in October 2021.

☐ I consent to my child's shoulder musculoskeletal screening information to be shared within this UCT research team to allow for analysis as described above.

I have fully read and understand the participant information sheet and have had the chance to ask questions relating to the procedures and outcomes of the tests used in this study.

I acknowledge that any information gathered throughout this study will be kept confidential; will only be used for purpose of scientific research; and that my child's personal information will not be made publicly available under any circumstances.

The potential risks and benefits associated with my child participating in this study have been thoroughly explained to me. I understand that I may choose to withdraw my child from the study at any point, without any consequences.

Finally, I consent to allow my child to take part in this study.

______________________	______________________	________
Full Name (please print)	Signature of Parent	Date
	______________________	________
Lianne Verwey	Signature of Student Researcher	Date
	______________________	________
Dr Janine Gray	Signature of Research Supervisor	Date

Appendix G: Informed assent form

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD
HEALTH SCIENCES

DHRS
Department of Health and Rehabilitation Sciences
FACULTY OF HEALTH SCIENCES

Divisions of Communication Sciences & Disorders • Disability Studies • Nursing & Midwifery • Occupational Therapy • Physiotherapy

F45 Old Main Building, Groote Schuur Hospital
Observatory, Cape Town, South Africa, 7925
Telephone: +27 (0) 21 406 6401
Website: www.dhrs.uct.ac.za

Dear Participant,

I am a master's student at University of Cape Town's Division of Physiotherapy. I am performing a study to identify risk factors that pre-dispose athletes to developing shoulder pain and whether these factors affect throwing performance, or not. All of the information gathered from this study will be used towards completing the research component of my MSc Exercise and Sports Physiotherapy degree. The Human Research Ethics Committee, at the Faculty of Health Sciences from University of Cape Town has ethically approved this study.

In order for you to take part in this study, you will need to provide informed consent by reading and signing this form. Please make sure you carefully read through this form and ask about anything that is unclear before you sign. You may ask your parents if you are unsure about anything to explain things further and if they aren't able to answer your questions then you are more than welcome to ask me.

Why is this study being done?

It is known that teenage water polo players are at a high risk for shoulder injuries. This is due to repeated and constant swimming as well as overhead throwing with extreme shoulder movements. This study aims to identify the risk factors that put teenage water polo players at higher risk of developing shoulder pain and whether or not this affects their throwing performance. Therefore, if these risk factors can successfully be identified through a number of pre-season screening tests (aimed at assessing the amount of movement your shoulder has, and how much muscle strength your shoulder has), an injury prevention programme can be developed, with the aim of decreasing injury risk for teenage water polo players while also maintaining or improving throwing performance.

Why are you being asked to take part in this study?

You are asked to take part in the study because you have been selected to represent WP water polo and are between the ages of 14 and 19. Teenagers are included in the study because they are at a high risk for developing a shoulder injury.

How many people will be included in this study?

We hope that at least 60 teenage water polo players will take part in this study.

How long will the study last?
Data will be gathered from the players after selection. They will be monitored for the preparation phase until the end of the Nationals tournament in December 2021.

Will you be paid to take part in the study?
No, you will not get any money for agreeing to take part in this study.

How do we decide if you are able to take part in this study?
You are able to take part in this study if you have been chosen for Western Province Water Polo A or B sides (or one of the non-travelling reserves), in the U14, 15, 16 and 19 age-groups for the 2021-22 season.

When will testing be done and how long will it take?
Testing will take place in two sessions in October. The screening tests will be performed at an indoor facility and the throwing performance tests will be performed during a pool session on a separate day. A date will be communicated as soon as we have confirmation.

Where will testing be done?
The screening tests will be done in an indoor venue in Cape Town. The throwing performance tests will be done in an outdoor swimming pool in Cape Town.

What happens if you choose to take part in this study?
You will be asked to take part in a screening session. This will happen before the pre-season starts. Your choice to take part in the study is completely up to you and will be always kept private (the WP coaches will not know about your decision to take part or not) and will not affect your position in the team at all.

You will also be asked to complete a questionnaire linked to your shoulder and ability to perform activities of daily living as well as sporting activities. You will also take part in a physical assessment where your mass, standing and sitting heights will be measured as well as a number of physical tests (shoulder movement, strength and flexibility). Lastly, you will take part in throwing performance testing where your throwing speed and accuracy will be assessed using a normal-sized water polo ball in the swimming pool. You will be made aware of the above testing procedures before the study begins and will also be given an opportunity to warm-up before some of the tests. Once the testing has been completed, injury checking will be done over the weeks before and during Nationals, where you will need to fill in a short online survey (at most 6 questions), every week, linking to your shoulder pain and training demands. Any concerns linking to the above process will be brought up and discussed.

The testing process that will be followed, is described below. Qualified clinicians will help you to perform all the tests and record the results. You will be asked to please wear shorts and a t-shirt during the screening tests but will need a costume for the throwing performance testing in the swimming pool.

1. Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score

This is a questionnaire that assesses the function, performance, arm/shoulder symptoms and interpersonal relationships and performance. There are three sections and a total of 19 questions. You will be asked to fill it in prior to the start of the study and again at the end of the study. It takes approximately 5 minutes to fill in.

2. Anthropometric Data

a. Body Mass

This will be measured with you standing barefoot and, in your shorts, and t-shirt on a scale.

b. Height

This will be measured firstly in standing, with you barefoot, heels against the wall, and, in your shorts, and t-shirt. Secondly, height will be measured in sitting, on a chair, 50cm above the ground and with your heels flat on the floor and back flat against the wall.

c. Maturation Assessment

The body mass, height and leg length measurements will be used to predict your fastest growth spurt and how close you are to that point.

3. Shoulder Specific Tests

The following tests will then be done on both your shoulders. These tests will be done in different positions including standing up, sitting down, lying on your back and on your tummy. It will take about 25 minutes to complete this.

a. **Pain Provocation Tests (used to test for the presence of shoulder pain by a yes/no answer):**
    i. Hawkin's-Kennedy Test
    ii. Jobe's Test/Empty Can
    iii. Full Can
b. **Pectoralis minor muscle (deep chest muscle) length**
c. **Shoulder joint rotation range of motion**
d. **Shoulder blade rotational range of motion**
e. **Muscle strength of shoulder rotator muscles**
    i. Internal (inward) rotators
    ii. External (outward) rotators
f. **Muscle strength of the hip stabilisers**
    i. Gluteus Medius
g. **Muscle strength of the shoulder blade stabilisers**
    i. Serratus Anterior muscle
    ii. Upper Trapezius muscle
    iii. Lower trapezius muscle
h. **Medicine Ball power throws**

4. **Throwing performance testing**

Throwing speed and throwing accuracy will be tested in the pool, aiming at goals using a standard-sized water polo ball.

5. **Injury Monitoring**

Throughout the water polo season until Nationals you will be asked to fill out a quick questionnaire on your shoulder pain, tiredness and strength and training. This will be done weekly on a shared google document. There will be 3 sections and take about 1 minute to fill in. The first will be about training, the second about shoulder pain and the third about shoulder strength. For this study, shoulder pain is defined as the moment you start to feel pain that lasts for a day or more. This can happen during training or a match and doesn't matter if you need to see a doctor or if you miss out on playing because of it or not. You will need to record this though. Shoulder strength will be defined as the shoulder feeling tired or weak, worsening your performance or the ability to perform an activity.

What are the downsides or negative effects (risks) of taking part in this study?

Taking part in this study is very safe, however a few small possible risks that could develop are:

- Shoulder pain lasting only a short time caused by the screening and throwing tests. This should go away after a few minutes, but you amount of pain will be checked during the process. However, if the pain does not go away or get better, or gets worse, the testing will be stopped immediately.
- For 48-72 hours after the testing, you might complain of muscle soreness in your shoulders and surrounding areas. This is not uncommon as many athletes feel this way after performing physical movements that they are not used to.

What are the upsides or positive outcomes (benefits) linked with taking part in this study?

All the testing results will be given to you for your own interest. You can use the results to identify any possible risks for shoulder pain and/or injury that you might have to better understand your shoulder's ability and 'health' and possible areas to improve performance. If you get shoulder pain or a shoulder injury during testing, you will be offered to be sent to a health care provider. We expect that the study findings will help in decreasing the number of injuries to the shoulder experienced by teenage water polo players. This can be done by explaining the possible risk factors linked with developing shoulder pain to coaches and helping them to form programs to try and prevent these injuries by focusing on the risk factors for shoulder pain.

It is important to note that UCT offers a no-fault insurance that will cover all participants if something goes wrong. Any trial-related injury corresponding to the British Pharmaceutical industry (ABPI) guidelines (1991) will be covered by the insurance with quick payment of compensation. These standards recommend that UCT, without any legal obligation, should compensate participants without the need of them proving that UCT is at fault. An injury caused by the study activities is considered trial related. Any injuries sustained during the trial, whether it is research-related, or a related complication should be made known to the study investigators immediately. UCT has the right to withhold compensation if, and to the extent that, the injury sustained was due to the participant's lack of following the instructions as explained while taking part in the study. The participant's right to claim compensation for injury where negligence is proved is not affected. Injury sustained during the water polo season is not covered by this insurance.

Please note that no physiotherapy treatment will be given to participant's if they do sustain an injury during the study. We will give advice and refer to relevant medical professional where appropriate.

What happens if you choose not to take part in this study?

Your decision to take part in this study is completely up to you. You will be able to leave the study at any point, without any reason or concern. Your decision will be kept private, and the Western Province coaches won't be able to find out and will not affect your selection in the team.

Who to ask if you have any questions or concerns linked to this study?

Please feel free to call or email me, the student researcher, or one of my supervisors, Dr Janine Gray or Prof Steve Roche if you would like to know more or are unsure of anything linked to the study. All calls or emails will be kept private.

Student researcher: Lianne Verwey
Cell number: 082 320 0090
Email: lianneverwey@gmail.com

Research supervisors:

Dr Janine Gray
Cell number: 082 4983178
Email: janine@thelockerroom.org.za

Prof Steve Roche
Cell number: 0837275454
Email: Stephen.roche@uct.ac.za

Please feel free to contact Prof Blockman if you have any ethical concerns or want to know more about your rights and wellbeing as someone taking part on this research study.

Tel number: 021 406 6338

Player assent form
The influence of intrinsic risk factors on shoulder pain and throwing performance amongst adolescent, provincial water polo players, in South Africa.

I, ________________________________, have been told about this study ('The influence of intrinsic risk factors on shoulder pain and throwing performance amongst adolescent, provincial water polo players, in South Africa') and understand what the study entails and what is expected of me to take part in this study.

Using an 'X', please mark, which sections of this study you are willing to take part in:

☐ I assent to take part in the shoulder musculoskeletal screening and throwing performance testing that will be done by UCT researchers and for me to fill-out an online survey every two weeks for three months to monitor for any shoulder pain and/or injuries throughout the season. I understand that I will perform a number of tests as mentioned above. I acknowledge that the testing procedure will be conducted at a designated venue in Cape Town in October 2021.

☐ I consent to my shoulder screening information to be shared within this UCT research team to allow for analysis as described above.

I have fully read and understand the participant information form and have had the chance to ask questions linked to the procedures and outcomes of the tests used in this study.

I understand that any information gathered during this study will be kept private; will only be used for the purpose of scientific research; and that my personal information will not be made available to the public under any circumstances.

The possible risks and benefits linked to me taking part in this study have been clearly explained to me. I understand that I may choose to leave the study at any point, without any reason or concern. If you would like to take part in this study, please complete the form below.

_______________________	______________________	________
Child's name and surname	Signature/initials of child	Date
	______________________	________
Lianne Verwey	Signature of Student Researcher	Date
	______________________	________
Dr Janine Gray	Signature of Research Supervisor	Date

Please note that your parent/legal guardian is also going to be told about this study. As they are your parent/legal guardian, they will also have to agree to let you take part in this study for you to be allowed to be in the study

Appendix H: KJOC questionnaire

Subject Code: _______________ **Date:** _____________

<u>Please answer the following questions related to your history of injuries to YOUR THROWING ARM ONLY: (please circle the answer)</u>

1. Is your arm currently injured? YES NO
2. Are you currently active in your sport? YES NO
3. Have you missed a game or practice time in the last year due to an injury to your shoulder or elbow?
   YES NO
4. Have you been diagnosed with an injury to your shoulder or elbow other than a strain or sprain? YES NO

If yes, please state the diagnosis: ______________________

5. Have you received treatment for an injury to your shoulder or elbow?
   YES NO

   If yes, what was the treatment? (Check all that apply)
   - ☐ Rest
   - ☐ Therapy
   - ☐ Surgery (please give a description)__________________________

<u>Please describe your level of competition in your current sport:</u> (Use National, Provincial, High school as choices)

6. What is the highest level of competition you've participated at? ___________________
7. What is your current level of competition? ______________________________________
8. If your current level of competition is not the same as your highest level, do you feel it is due to an injury to your arm? YES NO

Please **check ONE category** only that best describes your current status:

- ☐ Playing without any arm trouble
- ☐ Playing, but with arm trouble
- ☐ Not playing due to arm trouble

<u>Instructions to athletes:</u>

*The following questions concern your physical functioning during game and practice conditions. Unless otherwise specified, all questions **relate to your shoulder or elbow**. Please answer with an X along the horizontal line that corresponds to your current level.*

1. How difficult is it for you to get loose or warm prior to competition or practice?

Never feel loose during games or practice *Normal warm-up time*

2. How much pain do you experience in your shoulder or elbow?

Pain at rest *No pain with competition*

3. How much weakness and/or fatigue (i.e., loss of strength) do you experience in your shoulder or elbow?

Weakness/fatigue preventing any competition *No weakness, normal competition fatigue*

4. How unstable does your shoulder or elbow feel during competition?

"Popping out" routinely *No instability*

5. How much have arm problems affected your relationship with your coaches, management, and agents?

Left team, traded or waived, lost contract or scholarship *Not at all*

The following questions refer to your level of competition in your sport. Please answer with an X along the horizontal line that corresponds to your current level.

6. How much have you had to change your throwing motion due to your arm?

Completely changed, don't perform motion anymore *No change in motion*

7. How much has your throwing velocity and/or power suffered due to your arm?

Lost all throwing power *No change in velocity/power*

8. What limitation do you have in endurance in competition due to your arm?

Significant limitation (stopped throwing) *No endurance limitation in competition*

9. How much has your control (throwing) suffered due to your arm?

<——————————————————————————————>

Unpredictable control *No loss of control*

10. How much do you feel your arm affects your current level of competition in your sport (i.e.: is your arm holding you back from being at your full potential)?

<——————————————————————————————>

Cannot compete, must switch sports Desired level of competition

Appendix I: COVID-19 survey

Subject code: _____________ **Date:**____________

Signature: ________________ **Temperature: _________**

	YES	NO
1. In the last 14 days, have you tested positive for COVID-19 or received a diagnosis of COVID-19 from a health care professional?		
2. Are you currently awaiting pending COVID-19 results?		
3. In the last 14 days, have you had close contact or cared for someone who has been diagnosed with COVID-19?		

SYMPTOMS:

Are you experiencing any of the following symptoms?	**YES**	**NO**
Fever		
Cough		
Shortness of breath		
Sore throat		
Persistent headache		
Extreme fatigue		
Night sweats		
Body aches		
Loss of smell or taste Nausea/vomiting		
Diarrhoea		

Appendix J: Data collection sheets

Subject Code: ________________ **Date: ___________**

Dominant Hand: _________________

1. ANTHROPOMETRIC DATA

	1st measurement	2nd measurement
Mass		
BMI		
Standing Height		
Seated Height		
Maturity offset		
Age at PHV		

2. SPECIAL TESTS

Test	Dominant Arm	Non-dominant Arm
Hawkins/Kennedy Test		
Jobe's Test		
Full Can Test		

3. PASSIVE SHOULDER ROTATION RANGE OF MOTION

Range of Motion:	Dominant Arm		Non-dominant Arm	
	1st measurement	2nd measurement	1st measurement	2nd measurement
GH Internal rotation				
GH External rotation				

4. **MUSCLE LENGTH TESTS**

Muscle Tested:	Dominant Arm		Non-Dominant Arm	
	1st measurement	2nd measurement	1st measurement	2nd measurement
Pec Minor Length				
Pec Minor Index				

5. **UPWARD SCAPULA ROTATION (GH Abduction ROM)**

Range of Motion:	Dominant Arm		Non-Dominant Arm	
	1st measurement	2nd measurement	1st measurement	2nd measurement
45° abd				
90° abd				
135° abd				
180° abd				

6. **ISOMETRIC MUSCLE STRENGTH**

Muscle Tested	Dominant Arm		Non-Dominant Arm	
	1st measurement	2nd measurement	1st measurement	2nd measurement
GH Internal rotation				
GH External rotation				
Serratus Anterior				
Upper Trapezius				
Lower Trapezius				
Gluteus Medius				

7. MEDICINE BALL POWER THROWS

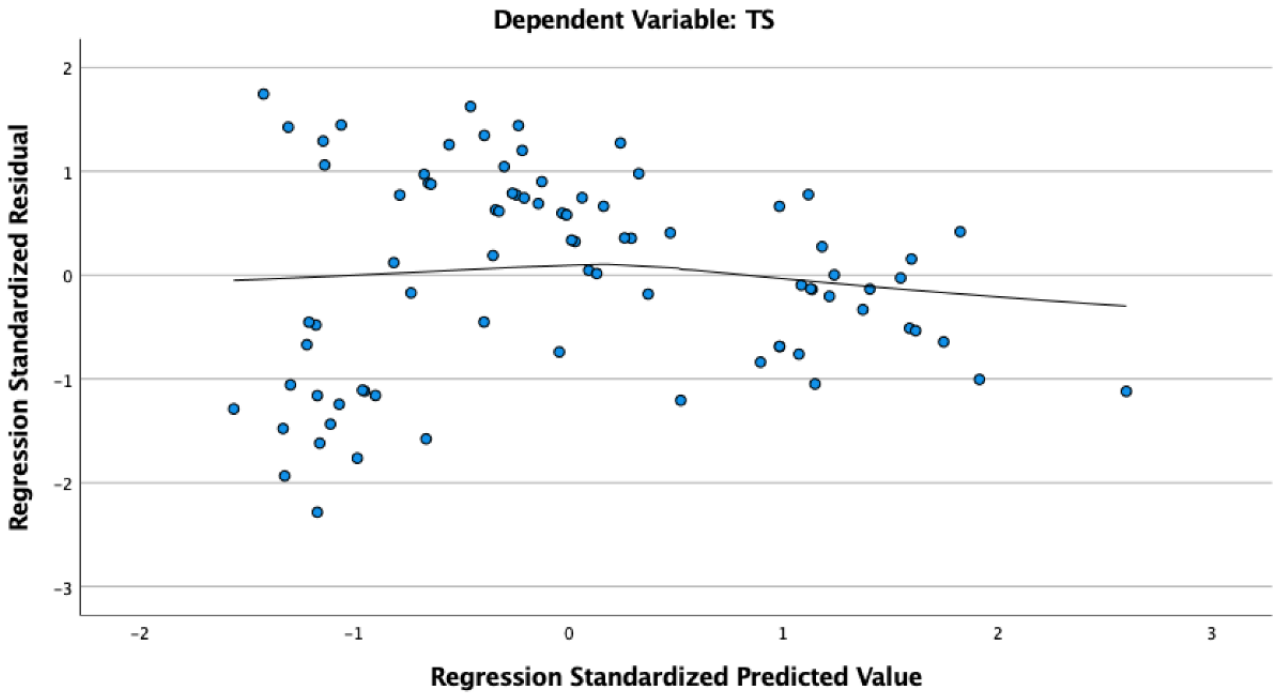
Attempt:	Distance in metres
Throw 1:	
Throw 2:	
Throw 3:	

8. THROWING PERFORMANCE TESTING

Throwing Speed	
Attempt:	Speed with radar gun:
Throw 1:	
Throw 2:	

Throwing Accuracy:	
Attempt:	Points Scored:
Throw 1:	
Throw 2:	
Throw 3:	
Throw 4:	
Throw 5:	
Throw 6:	
Throw 7:	
Throw 8:	

Appendix K: Throwing speed scatterplot with Gaussian Loess curve to prove homoscedacity



Appendix L: Throwing accuracy scatterplot with Gaussian Loess curve to prove homoscedacity