A Thesis prepared in fulfilment of the Master of Medicine in Exercise Science Degree

THROWING PERFORMANCE AND SHOULDER INJURY RISK IN ADOLESCENT MALE WATER POLO PLAYERS IN SOUTH AFRICA: EXPLORING ANTHROPOMETRIC AND MUSCULOSKELETAL PARAMETERS AND EVALUATING THE IMPACT OF A FOUR WEEK IN-SEASON CONDITIONING PROGRAM.

Student: Kelly (Candice) Mackenzie (BVNCAN001)

Supervisor: Dr Janine Gray

Co-supervisor: Prof Stephen Roche

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FACULTY OF HEALTH SCIENCES

DEPARTMENT OF HUMAN BIOLOGY
Division of Physiological Sciences
University of Cape Town

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Student name: Kelly (Candice) Mackenzie
Student Number: BVNCAN001
Signature: Signed by candidate
Date: 15/04/24

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COVID-19 disclaimer

The Covid-19 pandemic had a significant impact on my research in 2020 and 2021. Due to restrictions imposed on schools and school sports, I faced obstacles in conducting my testing and data collection and implementing the original study design.

Initially, the study was intended to follow a test-intervention-retest format. Our plan was to assess participants seven weeks before the water polo season began. Following that, we intended to carry out a six-week bi-weekly intervention program with a specific group. At the end of the six weeks (coinciding with the start of the season), we aimed to re-test the participants. The goal was to identify differences and draw conclusions between the groups after the six-week intervention period. Additionally, we intended to monitor participants throughout a three-month water polo season by utilizing a self-reported training load and pain log on Google Forms.

Testing was cancelled twice in 2021 due to covid-related reasons. The first being the national (government) restriction on sports participation and then a covid outbreak at the school over a six week period which then forced us to cancel the testing/data collection again. In January 2022, our testing schedule was unexpectedly altered. The school we had been using for testing commenced a summer sports camp earlier than anticipated. As a precautionary measure in case of any future Covid-related lockdowns or restrictions, we decided to conduct the tests immediately. This adjustment transformed the originally planned six-week pre-season exercise intervention into a six week in-season conditioning program.

Furthermore, due to changes in school sports activities, rugby training began in March, prompting us to modify our re-testing timeline. Rugby was introduced earlier in order to have a longer preseason after the decreased time exposure to rugby and contact in the two years prior due to Covid-19. Instead of the initially planned six-week interval, we were compelled to re-test participants after four weeks to avoid any potential interference from the rugby strength training.

In summary, the Covid-19 situation disrupted my research, leading to modifications in the study's design, testing schedule, and intervention timeline. These adjustments were necessary to accommodate the uncertainties and limitations imposed by the pandemic and ensure the integrity of the research.

Table of Contents

List of figures

List of tables

List of abbreviations

CKC	Closed kinetic chain
CKCUEST	Closed Kinetic Chain Upper Extremity Stability Test
Cm	Centimetre
DOMS	Delayed onset of muscle soreness
EMG	Electromyography
ER	External rotation
FINA	Fédération Internationale de Natation
GHJ	Glenohumeral Joint
GIRD	Glenohumeral internal rotation deficit
HAd	Horizontal adduction
HHD	Hand-held dynamometer
IR	Internal rotation
Kg	Kilogram
KJOC	Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score
MRI	Magnetic resonance imaging
MTS	Maximum throwing speed
OKC	Open kinetic chain
PHV	Peak height velocity
PMI	Pectoralis minor index
PML	Pectoralis minor length
ROM	Range of motion
TA	Throwing accuracy
TP	Throwing performance
TS	Throwing speed
USR	Upward scapula rotation
VAS	Visual analogue scale

Glossary of terms

Concentric strength	Muscle tendon complex working in its shortened state (Hody *et al.*, 2019).
Dominant	The preferred arm used for throwing or daily activity (Lust *et al.*, 2016).
Eccentric strength	Muscle tendon complex working in its lengthened state (Hody *et al.*, 2019).
Extrinsic risk	External factors relating to the sporting code or environment which are associated with injury (eg. Turf, coaching or equipment)(Wheeler *et al.*, 2012).
Glenohumeral internal rotation deficit	A loss (20° or greater) of internal rotation range of motion in the dominant versus non-dominant arm (Harput *et al.*, 2016; Keller *et al.*, 2018).
Humeral retroversion	The bony architecture that occurs when the head of the humerus is oriented in a posterior medial direction and is associated with a transverse plane rotation within the humerus (Greenberg *et al.*, 2015).
Intrinsic risk	An internal stressor from within the body specific to an individual or group that are associated with injury (eg age, weight and sex) (Wheeler *et al.*, 2012).
Kinetic chain	The linking and working together of several joints or segments of the body, in order to create movement (Ellenbecker and Aoki, 2020).
Overuse injury	An Injury or potential injury sustained from repetitive trauma over a period of time with the absence of a single identifiable cause (Aicale, Tarantino and Maffulli, 2018; Bell *et al.*, 2018).
Peak height velocity	The period of the fastest growth during puberty (Mills *et al.*, 2016).
Proprioception	Afferent sensory motor input from joint position sense, tension and force (Lust *et al.*, 2016; A. H. Hams *et al.*, 2019).
Risk factor	Behaviour of the athlete and the characteristics of the athlete, sport and environment that are associated with an increased chance of injury (Hopkins *et al.*, 2007; Wheeler *et al.*, 2012).

Scapula dyskinesia	Decreased scapular posterior tilt and increased scapula internal rotation with arm elevation (Struyf *et al.*, 2011; Pellegrini *et al.*, 2016).
Shoulder injury	A limitation in participation in training or matches due to symptoms experienced at the shoulder (Franić, M., Ivković, A., & Rudić, 2007; Ellapen *et al.*, 2013; Miller *et al.*, 2018).

Thesis abstract

Water polo is an action-packed and physically challenging sport which requires intense swimming, accurate throwing, and strategic grappling or wrestling for positioning in the water. The game involves two teams, with seven players from each side actively in the water at any one time. The primary objective is to score goals by propelling the ball through two goal posts, which are safeguarded by a goalkeeper. In contrast to other sports involving throwing, water polo players, excluding the goalkeeper, are restricted to using only one hand to interact with the ball at any given time. Consequently, catching and passing predominantly rely on the dominant arm whilst treading water. Although shoulder injuries are common, limited research exists regarding the specific factors that contribute to both sub-acute and chronic shoulder pain. Additionally, there is a dearth of evidence on the effectiveness of injury prevention interventions; programs designed to decrease the likelihood of injury and enhance performance. This novel research therefore aims to both; identify and understand the relationship between musculoskeletal parameters in adolescent water polo players and throwing performance and to investigate the effectiveness of a conditioning programme on musculoskeletal parameters associated with injury risk and throwing performance in adolescent water polo players.

The thesis includes one literature review and two original research papers. The literature review highlights that; shoulder injuries are pervasive in water polo across different ages and skill levels, but their underlying causes are not well-established. Despite the known benefits of exercise interventions in reducing injuries, enhancing throwing performance, and prolonging athletes' careers in various sports, these potential benefits remain insufficiently investigated in the context of water polo.

The first paper describes the relationship between musculoskeletal variables and throwing performance (TP); (throwing speed: TS and throwing accuracy: TA) in adolescent male water polo players. Musculoskeletal testing included strength, range of motion and stability measures, predominantly of the shoulder, that have been used previously to evaluate contributors to TP and screen for injury risk in a number of other overhead sports. TP was evaluated in the pool by testing the velocity of the throw with a radar gun and a novel test for TA. The aim of the second paper was to use the same sample group to investigate whether an in-season conditioning programme had an effect on musculoskeletal parameters associated with injury risk and TP.

Data collection involved four main sections. Firstly, demographic data, training and injury history, training load and shoulder functionality (KJOC test) was investigated by means of a questionnaire and this was completed by all participants. Musculoskeletal tests involving shoulder complex strength measures, shoulder range of motion, upward scapula rotation and scapula stability were conducted. A pool-based assessment of TS and TA was conducted as described above. The group of participants was then randomised into two groups (by computer generated numbering); Experimental and control. The experimental group engaged in a targeted conditioning program twice a week for four weeks. This program aimed to enhance strength and stability of the rotator cuff and scapula muscles, but also incorporated exercises for the core and legs. Participants, who were identified to have GIRD (posterior capsular tightness), were additionally provided with stretches for the posterior shoulder. The control group did only their pool-based water polo training. Finally, the same musculoskeletal testing was repeated after the four week period with all

participants. To investigate the association between musculoskeletal parameters and TP, bivariate and multivariate linear regression analysis was conducted. Bivariate analysis was used to analyse the effects of the conditioning program and factors associated with injury risk.

Chapter 3 documents the association of musculoskeletal variables and predicting TP. Five of the 15 variables correlated with TP. Age (15; p=0.007, 16; p=0.012, 17; p=0.062) correlated with TS. The average speed increased with each year of age (14 year old average TS: 50.56km/h, 15 year old average TS: 59.4km/h, 16 year old average TS: 59.9km/h, 17 year old average TS: 60.5km/h). Three other measurements in the dominant arm correlated with TS. These included posterior capsule tightness (p=0.015), glenohumeral internal rotation strength at 90° (p=0.022) and pectoralis minor length (p=0.032). For every increase of 1° in posterior capsule flexibility there was an associated increase in speed of 0.30km/h (95% CI: 0.06-0.54). For every 1N increase in shoulder internal rotation strength there was a 0.04km/h (95% CI: 0.00-0.08) increase in TS. For every 1cm increase in pectoralis minor muscle length there was an associated increase of 1.2km/h in TS (95% CI: 0.11-2.42). The CKCUEST (p= 0.030) correlated with TA, with 1 point increase giving a 0.01 improvement in accuracy score (95%CI: -0.003-0.002).

Chapter 4 documents the effect of the four week conditioning program on TP and injury risk. The results indicated that there were no significant differences between the two groups (p <0.01) for any of the musculoskeletal variables or TP variables after the four week exercise intervention period. Pain reported over the four week period was matched between the two groups. The largest number of participants experienced pain during week one and this gradually decreased by week four. Most of the reported pain was attributed to throwing, but no participants were excluded from the study due to shoulder pain. The intervention group maintained their TS, while the control group saw a slight reduction. Both groups showed some improvement in TA, but the improvements did not indicate a meaningful association between the investigated variables.

In conclusion the measurement of specific musculoskeletal variables in the adolescent water polo population may be useful in determining areas for an intervention to improve TP. Age, dominant arm posterior capsule length, glenohumeral internal rotation strength and pectoralis minor length correlated with TS. Shoulder stability (CKCUEST) correlated with TA. This highlights the importance of including these identified modifiable factors into future conditioning programs to possibly improve TP in adolescent water polo players. However, the four week conditioning program did not significantly change the musculoskeletal profile of the intervention group or influence the throwing performance or pain of male adolescent water polo players. The benefits of this intervention programme need to be studied over a longer period of time or as part of a pre-season conditioning programme to assess potential efficacy of an exercise programme of this nature.

Chapter 1
Introduction and scope of thesis

1.1 Introduction

Water polo is a physically demanding sport with unique challenges for athletes, differentiating it from other overhead sports. The aquatic nature, coupled with the head up swimming action, places distinctive biomechanical stress on water polo players' shoulders (Webster, Morris and Galna, 2009). In recent years, both internationally and in South Africa, water polo has gained momentum in popularity and participation. With the growing number of participants, the prevalence of musculoskeletal injury has also increased significantly (Ellapen *et al.*, 2013; Steffen *et al.*, 2013; Mountjoy *et al.*, 2014; Mountjoy, Miller and Junge, 2019).

In a study looking at high school (adolescent) male water polo players in South Africa, a prevalence of 51% of musculoskeletal shoulder pain over a 12 month period was found (Ellapen *et al.*, 2013). These numbers correspond with international injury surveys on water polo athletes, where the prevalence of shoulder pain has been reported as 38-80% (Webster, Morris and Galna, 2009). How many of these athletes play water polo with pain or injury is not clear. The prevalence of shoulder injury in water polo is primarily associated with overuse resulting from the cumulative stresses of swimming, throwing, and defending, and is of particular concern among adolescent players (Webster, Morris and Galna, 2009; Bliven *et al.*, 2021; Croteau, 2021; Orringer and Pandya, 2021).

The incidence of shoulder injuries in water polo is comparable to other sporting codes such as swimming, tennis and handball (Cools *et al.*, 2010, 2015; Andersson *et al.*, 2017; Tate *et al.*, 2017; Keller *et al.*, 2018) but is higher than volleyball and cricket (Giles and Musa, 2008; Reeser *et al.*, 2010; Dutton, 2012).

There is limited evidence in general on water polo injury risk factors and the efficacy of intervention protocols (Webster, Morris and Galna, 2009) and even less evidence for the adolescent age group (Ellapen *et al.*, 2013; Worsley *et al.*, 2013; Gradidge *et al.*, 2014; J. Zaremski, Zeppieri and Tripp, 2019). Moreover, a rule change in 2005 led to a faster game and increased throwing frequency, highlighting the need to identify specific musculoskeletal factors for TP enhancement and injury prevention (Miller *et al.*, 2018).

The current understanding of overhead TP and injuries in water polo athletes is limited due to insufficient information and research. Although there have been numerous studies investigating TP and injuries in baseball, handball, cricket, and other overhead sports, it remains uncertain whether the findings from these studies can be directly applied to water polo athletes (Freeston *et al.*, 2016; Lust *et al.*, 2016; Reinold *et al.*, 2018; Sakata *et al.*, 2019; Ahmed, Brown and Gray, 2020; Djanis, 2021; Melugin *et al.*, 2021; Oranchuk, Ecsedy and Robinson, 2021).

TS and TA are essential components of overall TP. These performance outcomes are influenced by both musculoskeletal and cognitive factors related to motor learning. Previous studies have indicated that water polo, baseball and handball athletes who exhibit better shoulder complex, trunk (core), and lower limb strength and stability tend to have superior TP (McCluskey *et al.*, 2010;

Ferragut *et al.*, 2011; Platanou and Veramenti, 2011; Palmer *et al.*, 2015; Ortega-becerra, Pareja-blanco and Jiménez-reyes, 2017; Sakata *et al.*, 2019; Oranchuk, Ecsedy and Robinson, 2021; Noronha *et al.*, 2022).

The purpose of this thesis was threefold: first, to review the existing literature in water polo and additional overhead sports, to identify what is currently known about musculoskeletal predictors of throwing performance and injury and the efficacy of exercise intervention programmes aimed at improving performance and preventing injury (Chapter 2). Second, to examine the musculoskeletal parameters related to TP (Chapter 3); third, to assess the impact of an in-season exercise intervention program on shoulder injuries and TP in male adolescent water polo players in Grahamstown/Makhanda, South Africa (Chapter 4).

Conducting this study on adolescent water polo players is crucial due to the prevalence of shoulder injuries in this age group. Existing research on the topic is limited and inconclusive, highlighting the need for more comprehensive studies specifically targeting adolescents. Better understanding the effectiveness of conditioning programs in reducing injury risk and improving performance in this demographic is essential for optimising their athletic development and well-being.

To end, the findings of the study will be summarised and discussed (Chapter 5). There is limited research in this area in water polo and therefore the evidence will be presented as a narrative review using supporting evidence where necessary from other overhead sports.

1.2 Aims and outcome measures

1.2.1 Aims

The aim of this study was to identify anthropometric and musculoskeletal parameters associated with throwing performance in adolescent water polo players. Furthermore, the efficacy of an in-season conditioning programme was assessed in relation to musculoskeletal risk factors, throwing performance and injury risk. Specifically, the study aimed to identify:

i. Musculoskeletal and anthropometric parameters associated with throwing performance (Chapter 3).
ii. Whether the conditioning program designed for this study was effective in changing musculoskeletal risk factors traditionally associated with an increased relative risk of developing shoulder injury in overhead throwing athletes (Chapter 4).
iii. The effects of the conditioning on throwing performance including speed and accuracy (Chapter 4)
iv. The effect of the conditioning on shoulder injury in water polo players over a 4 week water polo season (Chapter 4).

1.2.2 Outcome measures

Primary outcome measures:

1) Musculoskeletal factors:
   a) Overhead function and athletic performance of the shoulder (Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score)
   b) Impingement tests:

    i) Hawkins-Kennedy
    ii) Neer's
    iii) Jobe's
c) Range of motion of:
    i) Upward scapula rotation (USR)
    ii) GHJ internal and external rotation (GIRD)
d) Strength of:
    i) GHJ internal and external rotators
    ii) Scapula stabilisers (Serratus Anterior, Lower Trapezius and Upper Trapezius)
e) Length of:
    i) Pectoralis Minor
    ii) GHJ posterior capsule
f) Shoulder stability
    i) Closed kinetic chain Upper extremity stability
g) Throwing performance (Speed and accuracy)

Secondary outcome measure:

Workload and non-specific shoulder pain and/or injury data was monitored with a weekly Google forms document completed by the players. This weekly questionnaire aimed to monitor each players shoulder function during the four week conditioning period.

Chapter 2
A review of the literature

2.1 Introduction

Water polo originated in the mid-19th century in England and Scotland, where it was introduced as an aquatic form of rugby (Miller *et al.*, 2018). Dating back to the 1900's, water polo is the oldest standing Olympic team sport (Spittler and Keeling, 2016; Stromberg, 2017; Miller *et al.*, 2018; Hams, Witchalls and Adams, 2019). Water polo is a fast paced, physically demanding, contact game that can be broken down into swimming, throwing and jostling or wrestling for position in the water. Unlike other throwing sports, water polo players (except for the goalkeeper) may only ever have one hand in contact with the ball at any given moment, so catching and passing is predominantly done, using the dominant arm (Spittler and Keeling, 2016). The rising popularity of water polo, has brought about increased participation along with a notable surge in musculoskeletal injuries due to the growing number of participants (Webster, Morris and Galna, 2009; Ellapen *et al.*, 2013; Gradidge *et al.*, 2014; Spittler and Keeling, 2016; Stromberg, 2017; Miller *et al.*, 2018; Jameson, 2020; Tully, 2022). Despite the high prevalence of these injuries, there is minimal research available on specific contributing factors on sub-acute and chronic shoulder pain (Spittler and Keeling, 2016) as well as a lack of evidence on the effectiveness of an injury prevention intervention programme aimed at reducing the risk of injury and improving performance (Mountjoy *et al.*, 2014).

This review will present existing evidence on the epidemiology and aetiology of risk factors for injury in water polo and discuss relevant intervention programmes in overhead athletes for their applicability to a water polo player.

2.2 Physical and biomechanical demands of water polo

Water polo is physically challenging and the demands placed on the athlete are unique in numerous ways, due to the athlete being submerged in water. The biomechanical and physical demands of head-up swimming, throwing and treading will be discussed below.

2.2.1 Swimming biomechanics

Water Polo players swim predominantly with a modified, upright freestyle stroke, with their heads and elbows above the water level and the ball floating on a wave of water in front of them which they control with their forearms. This adapted "head-up" swimming stroke, eliminates the body roll and puts an increased amount of strain on the neck, shoulders and other surrounding soft tissue structures compared to the standard freestyle stroke. The shoulder is abducted and elevated with full internal rotation during the catch phase of the stroke (Ellapen *et al.*, 2013; Stromberg, 2017; Hams *et al.*, 2018; Miller *et al.*, 2018). Swimming in a "head-up" position, with the ball, showed the greatest obliquity of the body and greatest depth of the feet during kicking, indicating both an increased physical demand on the shoulders and need for power from the lower limbs (Jesus *et al.*, 2012) . The elimination of the body roll, increases abduction of the shoulder which in turn increases the risk of posterior impingement and increased translation of the humeral head due to rotator cuff fatigue (Stromberg, 2017).

The players swim in short bursts of varying intensity lasting up to 15 seconds, followed by lower intensity intervals of up to 20 seconds (Franić, M., Ivković, A., & Rudić, 2007; Noronha *et al.*, 2022) and a direction change (on average) every 6.2 seconds (Miller *et al.*, 2018). Between swimming intervals (47% of the game), they use a modified breast stroke kick called eggbeater kick, to tread and keep themselves afloat (Brooks, 1999; Webster, Morris and Galna, 2009; Noronha *et al.*, 2022).

2.2.2 Throwing biomechanics

There are two different variants of throwing in water polo, namely passing and shooting. Passing is a much lower velocity action which is generally used to transfer the ball from one team mate to another, whereas shooting is a much more powerful action, used for scoring goals past a goalkeeper (Spittler and Keeling, 2016). Throwing usually involves a proximal to distal sequence in the kinetic chain in order to generate power in the throw, but in water polo, the athlete is submerged in water and must generate this force without a stable base (Webster, Morris and Galna, 2009; Miller *et al.*, 2018). The normal rotation of the body that would occur in the throw is frequently impeded by a defending player, adding to the difficulty of the throw (Stromberg, 2017). The ball is thrown in an overhead motion at high velocities of approximately 60-90km/h and can be caught by another player or even blocked by a hand or arm from close range, which causes high forces in the upper limb of the blocker (Webster, Morris and Galna, 2009; Spittler and Keeling, 2016; Stromberg, 2017; Miller *et al.*, 2018).

During a single game, each player throws the ball an average of 38.7 times, receives the ball 32.1 times and takes 7.9 shots at goal (Hams *et al.*, 2019). The overhead throw is used as it has been found to be the most accurate and powerful way to throw or shoot the ball for water polo players as the rest of their body is submerged in water (Esfehani *et al.*, 2014).

The throw in water polo can be broken down into three phases (Figure 2-1); Preparation and Backswing phase (cocking), forward swing to ball release phase and follow through phase (Alexander, Hayward and Honish, 2010).

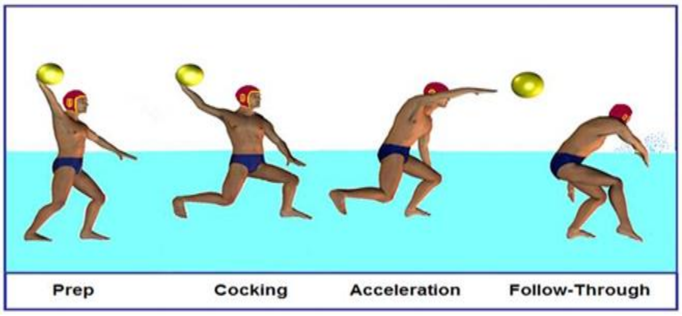

Figure 2-1 The phases of the water polo throw.
Note. From Water polo planet, by J. Solum, 2010 (http://www.waterpoloplanet.com/HTML_Jim_pages/js23_shot_doctor_jim.html) Copywrite 2009 Jim Solum.

Land based sports such as baseball and cricket have different phases of throwing due to the lower limbs and core providing a stable base of support (Chu *et al.*, 2016). The baseball pitch is traditionally broken up into six phases of throwing; wind up, stride, arm cocking, acceleration, deceleration and follow-through. The legs provide 51% - 55% of the kinetic energy that is transferred to the arm and hand, highlighting the importance of an efficient kinetic chain (Chu *et al.*, 2016). Nonetheless, cricket bowling and baseball pitching have previously been found to have different musculoskeletal profiles (Tully, 2022). In water polo, the shoulder (glenohumeral joint) frequently assumes a higher degree of abduction while executing throwing or passing actions to elevate the elbow from the water, minimize resistance, avoid a defender and amplify force, demonstrating a distinct throwing technique that is done in varying ranges of abduction (Figure 2-2) (Webster, Morris and Galna, 2009; Spittler and Keeling, 2016; Stromberg, 2017; Miller *et al.*, 2018).

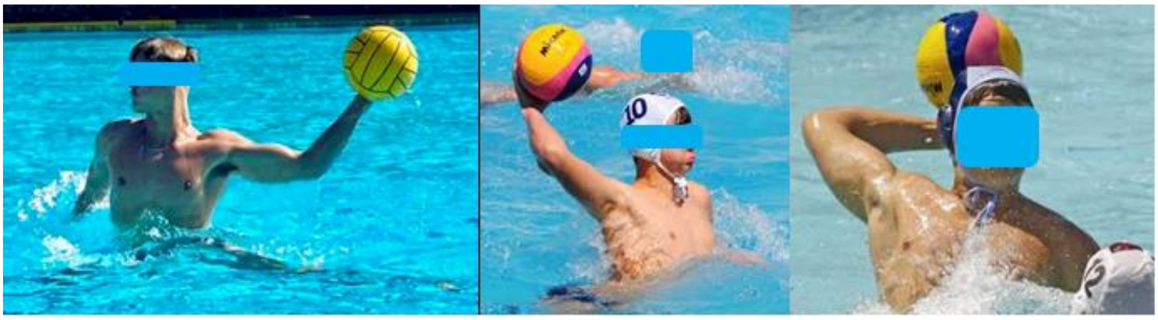

Figure 2-2 Examples of shoulder positions during throwing

In water polo, the Preparation and Backswing phase begins with the player applying a downward pressure on the ball. Backswing begins with the ball being picked up; the shoulder is extended, abducted and externally rotated with the elbow in flexion and the scapula retracted. The trunk is initially rotated towards the throwing arm to achieve maximal external rotation (Alexander, Hayward and Honish, 2010; Bakshi and Freehill, 2018). Initially, there is activation of the deltoid, supraspinatus and infraspinatus to achieve glenohumeral external rotation. At full external rotation, the subscapularis, latissimus dorsi, pectoralis major and teres major eccentrically contract to exert an anterior stabilising force on the glenohumeral joint (Bakshi and Freehill, 2018).

There are two schools of thought with regards to what the pathological process may be during cocking in terms of humeral translation. One view is that there is postero-superior translation of the humeral head caused by thickening/tightening of the posterior capsule and therefore development of internal impingement (impingement occurring between the posterior glenoid rim, supraspinatus and infraspinatus at the insertion at the posterior greater tuberosity). The other view is that with the repeated abduction and external rotation, there is repeated anterior-inferior translation of the humeral head which causes stretching of the anterior capsule and therefore instability resulting in impingement (Klein *et al.*, 2014; Stromberg, 2017; Miller *et al.*, 2018).

The acceleration phase is defined as the period of time between full external rotation and the point of ball release. From relative hyper extension, the trunk moves into a more flexed position. Hams *et al*., (2019) describe a proximal to distal trunk sequencing that contributes 30%-35% of ball acceleration. The shoulder now flexes, adducts and internally rotates with the elbow moving into extension and the scapula into protraction before the ball is released. The subscapularis, pectoralis major and latissimus dorsi work hard in this phase in order to achieve internal rotation of the humerus and influence the ultimate ball velocity (Bakshi and Freehill, 2018).

Deceleration and follow through phase sees the shoulder continuing to flex, adduct and internally rotate even after the ball is released to the end of the follow through phase. The shoulder then reaches maximum internal rotation and will experience the greatest stress on the posterior capsule at the end of this phase contributing to the posterior capsular tightness or contracture (Alexander, Hayward and Honish, 2010; Bakshi and Freehill, 2018). This is often considered the most “dangerous phase" of throwing, because of the distraction and sheer forces that are exerted on the glenohumeral joint. Any energy not imparted on the ball, is absorbed by the shoulder joint and posterior shoulder in an attempt to decelerate the arm (Bakshi and Freehill, 2018). The posterior shoulder withstands distraction forces of up to 108% of the athlete's body weight at this point (Kinsella *et al.*, 2014).

The biceps and brachialis contract in order to decelerate elbow extension (Bakshi and Freehill, 2018). This forceful biceps contraction can cause injury at its superior insertion on the superior glenoid labrum (Chang and Polster, 2016). Horizontal and internal rotation torque in the penalty throw is 64Nm and 59Nm respectively (Miller *et al.*, 2018).

2.2.3 Treading biomechanics

Water polo players keep themselves afloat by using a vertically directed rotatory kick under water called "eggbeater kick". This is a cyclical motion, using alternating motions of the lower leg, comparable to an eggbeater. This eggbeater kick can maintain the player at a constant height out of the water, but the player may jump or lunge in various directions using a powerful simultaneous modified breast stroke kick especially when shooting (Sanders, 1999; Spittler and Keeling, 2016).

If an athlete lacks leg strength and/or endurance, they will not be able to maintain their body position out of the water or achieve the required trunk rotation needed for effective and powerful passing or shooting. The elbow may also drag through the water during a pass or a shot, creating further resistance and strain on the shoulder joint. There is a positive correlation between leg strength and throwing velocity, which shows the importance of having a strong and functional kinetic chain (Zinner *et al.*, 2015).

2.3 Epidemiology of injuries

Water polo is a unique sport, in that it comprises of a combination of high load overhead throwing and swimming. Bearing the risks of both swimming and throwing components, the high incidence of injury is understandable, even though there is a lack of good quality evidence for this (Mountjoy *et al.*, 2010; Ellapen *et al.*, 2013; Hams, Evans, Adams, *et al.*, 2019a; Mountjoy, Miller and Junge, 2019; Jameson, 2020; Tully, 2022).

2.3.1 Epidemiology of shoulder injuries in other overhead sports

Overhead sporting codes that make use of high velocity repetitive end range shoulder movements are sports such as swimming, volleyball, cricket, tennis, handball and baseball (Cools *et al.*, 2015; Harput *et al.*, 2016; Andersson *et al.*, 2017; Struyf *et al.*, 2017; Keller *et al.*, 2018; Dutton, Tam and Gray, 2019; Kekelekis *et al.*, 2020; Takagishi *et al.*, 2020). Incidence of shoulder injuries in water polo is similar to incidences found in swimming, tennis and handball (Cools *et al.*, 2015; Andersson *et al.*, 2017; Struyf *et al.*, 2017; Keller *et al.*, 2018; Dutton, Kekelekis *et al.*, 2020) but is higher than in volley ball and cricket (Giles and Musa, 2008; Reeser *et al.*, 2010; Dutton, Tam and Gray, 2019). The prevalence of shoulder pain was the highest in elite handball players (44%-75%) (Andersson *et al.*, 2017; Fredriksen *et al.*, 2020) and high school soft ball pitchers (61%) (J. Zaremski, Zeppieri and Tripp, 2019) followed by adolescent elite tennis (20%-49%) (Cools *et al.*, 2010; Kekelekis *et al.*, 2020) and then college volleyball (43%) (Reeser *et al.*, 2010). Lower levels of prevalence were found in international first class cricket (5.2% to 23%) (Orchard *et al.*, 2002; Stretch and Venter, 2003; Ranson and Gregory, 2008; Dutton, Tam and Gray, 2019) and adolescent cricket age groups (17% to 23%)

(Noorbhai *et al.*, 2012; Dube, Gundani and Rastogi, 2018). Similarly, 23% of high school handball players had pain (J. Zaremski, Zeppieri and Tripp, 2019). Youth club baseball was the lowest, with a prevalence of 13.6% (Takagishi *et al.*, 2017, 2020).

In a systematic review looking at shoulder injuries in youth sports, Gibson *et al.*, (2022) found a 10.9% prevalence (median). It was also apparent that shoulder injuries occurred more in practice than competition, likely due to the repetitive nature of practicing these overhead throwing movements.

2.3.2 Epidemiology in swimming

Recreational swimming is known for being low impact and having minimal injury risk. This is not the case in competitive swimmers due to the repetitive overhead movement in all of the swimming strokes, some completing more than 2500 shoulder revolutions per day (Sein *et al.*, 2010).

There is a high prevalence of shoulder pain in adolescent competitive swimmers (Mcmaster, Roberts and Stoddard, 1998; Walker *et al.*, 2012; Bailon-Cerezo, Torres-Lacomba and Gutierrez-Ortega, 2016; Struyf *et al.*, 2017; Tessaro *et al.*, 2017; Mclaine, Bird, *et al.*, 2018). The prevalence ranged from 18% to 54% which is much higher than observed in other age groups. Adolescent swimmers are exposed to the greatest load and a study by Tate *et al.*, (2017) showed a positive correlation between upper limb usage, and pain, dissatisfaction and disability. Seventy two percent of an adolescent swimming population reported to have used pain medication in order to manage their pain during swimming practice, with 89% in the same group seeking medical treatment for their shoulder pain (Struyf *et al.*, 2017).

2.3.3 Epidemiology in water polo

Water polo is a physically demanding game from the eggbeater kick and overhead throwing and shooting of the ball, as well a high level of swimming proficiency. The only compulsory protective gear that is worn is a material based water polo cap which has built-in protective malleable ear muffs, leaving the rest of the body exposed to direct contact from other athletes and/or the ball itself. The throwing velocity of the water polo ball has been recorded at speeds of 60-70km/hour which can be a potential cause of acute traumatic injury (Webster, Morris and Galna, 2009; Spittler and Keeling, 2016; Stromberg, 2017; Miller *et al.*, 2018).

During the 2004 Olympic Games, 53% of injuries sustained by water polo players were reported to involve the head and neck, 12% the trunk and 6% involved the shoulder (Miller *et al.*, 2018). All of these injuries were either contact related or resulted from foul play (Stromberg, 2017).

At the 2009 FINA world Championships, upper limb injuries in water polo players were found to be the highest of all aquatic sports, comprising 37% of the total injuries. Of these injuries, 19% involved the head and neck and 12.5%, the shoulder (Miller *et al.*, 2018). Similarly, head and shoulder injuries were also found to be the most common water polo injuries in adolescents in a review by Orringer and Pandya, (2021). It appears that the shoulder injury rates doubled over a five year period, during major international tournaments. There was however a rule change in 2005 that resulted in a faster game and increased throwing frequency which may be a contributing factor in this increased injury trend (Miller *et al.*, 2018).

In an analysis of water polo injuries from FINA World Championships (2009, 2013, 2015, 2017) and Olympic games (2004,2008,2012,2016), it was found that shoulder injuries were the fourth most common type of injury with an incidence of 11.3% (Mountjoy, Miller and Junge, 2019). Over a 15 year study period, collegiate players in the USA report 11.5% incidence of shoulder injuries (Sallis *et al.*, 2001) which was similar to a 6.1-13.6% period prevalence found in a systematic review by (Croteau, 2021). A study at the FINA aquatics world championships (2013) investigated injuries for four weeks prior to the competition and during the competition period itself. They found that 68.4% of water polo athletes trained and competed with injuries, with 44.1% of athletes admitting that it affected their athletic performance.

In high school adolescent, water polo boys there was a 51% prevalence of musculoskeletal shoulder pain reported over a 12 month period (Ellapen *et al.*, 2013). In a review of notes on shoulder injuries in adolescent water polo players from a five year period (2016-2021), it was found that 41% of athletes had had shoulder pain and that 48% was acute pain (Orringer and Pandya, 2021). These numbers correspond with other international injury surveys, where water polo shoulder injury prevalence was found to be 38-80% (Ellapen *et al.*, 2013; Orringer and Pandya, 2021). How many of these athletes play water polo with an injury is not clear.

The high incidence and prevalence of shoulder injuries in overhead sport athletes does seem to suggest that the repetitive overhead action of the sport may place the athlete at risk and that water polo carries a similar risk observed in other overhead sports.

2.4 Types of injury

The injuries seen in overhead athletes are unique, due to the mechanics required by the shoulder in these sports (Edmonds and Dengerink, 2014). Impingement is used as a blanket term for a number of painful symptoms and is not "pathology" on its own. Underlying symptoms may be due to; Rotator cuff pathology, scapular dyskinesis, shoulder instability, biceps pathology and SLAP lesions and GIRD (Cools, Cambier and Witvrouw, 2008).

MRI, clinical tests and arthroscopic investigation (done on 11 water polo players with shoulder pain) revealed internal impingement, thought to be from the repetitive movements in the extremes of shoulder range (external rotation/abduction). Changes to the subscapularis and infraspinatus tendons, and posterior labrum were also noted, in comparison to age matched controls. However, only 29% of these players with tissue changes were symptomatic (Klein *et al.*, 2014).

Rotator cuff pathology is common in overhead throwing athletes especially in their dominant shoulder (Bakshi and Freehill, 2018). However, 40% of overhead throwing athletes found to have partial or full thickness rotator cuff tears (on MRI) were asymptomatic, and when these athletes were interviewed five years later they were all still asymptomatic and doing well (Bakshi and Freehill, 2018). Impingement is often mentioned in water polo shoulder studies as a common injury, but there have not been specific pathologies identified and little is known about the true prevalence of these pathologies. Impingement related pathology is well researched in other overhead sports (Drakos *et al.*, 2009; Yanai, 2018; Laudner *et al.*, 2020).

Rotator cuff tears aren't particularly common amongst the adolescent population, however partial articular supraspinatus tendon avulsion (PASTA) and Superior Labrum Anterior and Posterior (SLAP) tears are. SLAP tears are the most common labral pathology found in overhead athletes and can be attributed to unresolved internal impingement (Edmonds and Dengerink, 2014) and GIRD (Bakshi and Freehill, 2018). On arthroscopic examination of overhead athletes of mixed populations in theatre, 83% to 91% had SLAP lesions (Andrews, Broussard and Carson, 1985; Reinold *et al.*, 2003). Chronic and acute/traumatic labral degeneration and tears have been reported in the water polo and swimming population (Borsa *et al.*, 2005; Croteau *et al.*, 2021).

A Bennet lesion presents with a bony exostosis at the posterior-inferior glenoid. These lesions are thought to be caused by traction on the posterior capsule and triceps tendon during the deceleration and follow through phase of throwing, posterior impingement of the humeral head on the glenoid labrum during late cocking and/or wringing action during acceleration phase (Bakshi and Freehill, 2018). Bennet lesions, commonly found in overhead throwing athletes, particularly those with associated conditions like glenohumeral internal rotation deficit (GIRD) and internal impingement, are typically initially asymptomatic, but can eventually cause symptoms and impact throwing performance (Bakshi and Freehill, 2018). Male baseball pitchers have a prevalence of 22% to 47% for Bennet lesions but have not yet been reported in water polo players (Wright and Paletta, 2004; Nakagawa *et al.*, 2006; Park, Noh and Chung, 2016).

Laxity has been defined by Struyf *et al.*, (2017) as the "increased translation of the humeral head without any shoulder pain." If this laxity leads to pain, it is known as pathological laxity/glenohumeral instability. Instability refers to "any structural or functional deficit in the glenohumeral joint leading to pathologic movement of this joint" as well as "symptomatic laxity" (Tessaro *et al.*, 2017). Shoulder laxity in swimmers is common and predisposes swimmers to shoulder pain (Struyf *et al.*, 2017). Water polo players have been found to have increased range of motion at the shoulder, especially ER, however it is not clear whether this increased range of motion is associated with laxity and pain in this group.

2.5 Risk factors

The literature available for the identification of risk factors for shoulder injuries in overhead athletes is limited for all overhead sports (Cools *et al.*, 2015).

2.5.1 Intrinsic factors

Sport-specific adaptations during adolescence may occur because children start high-performance sports and specialise during early childhood (Cools, Palmans and Johansson, 2014). A phenomenon, often referred to as the "throwers paradox," highlights the necessity for the shoulder joint to possess both maximum mobility for effective throwing and optimal stability to prevent injuries. An imbalance in these requirements could potentially lead to sports-related injuries (Wilk *et al.*, 2016).

2.5.1.1 Non-modifiable Intrinsic factors

Increasing age is a non-modifiable risk factor commonly associated with shoulder injury (Reeser *et al.*, 2010; Cools *et al.*, 2015). Older amateur, elite and first division football players were found to be at higher risk of hamstring injury compared to their younger counterparts (Arnason *et al.*, 2004; Engebretsen *et al.*, 2010). This was also found to be the case in patients with non-specific low back pain (Maher, Underwood and Buchbinder, 2017) with pain worsening until the third decade of life, after which it then declines again (Hoy *et al.*, 2010).

The influence of gender as a risk factor for shoulder injury is not clear as there is only limited evidence to support higher injury risk in male high school and college lacrosse players. There were no sex differences in college tennis and elite handball players but a higher risk of injury in female high school water polo players was identified (Asker *et al.*, 2018).

Self-reported shoulder and hip pain correlated in an in-season cross sectional study in water polo players (Girdwood *et al.*, 2021). Current shoulder pain was found to be a risk factor for groin/hip pain and vice versa. Being the first group to quantify hip and shoulder pain in water polo players, the results show the importance of training or assessing the whole kinetic chain in throwing sports.

While previous injury has been strongly associated with injury in athletes sustaining a hamstring injury, this relationship has not been clearly demonstrated in shoulder injury. There has been limited evidence to show that previous injury increased shoulder injury risk in junior baseball pitchers (Asker *et al.*, 2018).

2.5.1.2 Modifiable Intrinsic risk factors

Decreased proprioception at the shoulder may delay the neuromuscular protective reflex and therefore the control of the rotator cuff may not be sufficient to protect the joint from excessive movement. Repeated micro-trauma and damage to the capsule impairs mechanoreceptors and therefore increases proprioceptive deficits and in turn, increases injury risk in water polo players (Mota and Ribeiro, 2012). Functional stability of the shoulder relies on effective motor control which is a product of good proprioception and appropriate strength (Mota and Ribeiro, 2012). A negative correlation exists between joint position sense and shoulder external rotation strength at 30° of external rotation in water polo players (Mota and Ribeiro, 2012).

Kyphotic postural profiles in high school age water polo players was linked to shoulder pain (Ellapen *et al.*, 2013; Gradidge *et al.*, 2014; Struyf *et al.*, 2017). Tight pectoralis muscles and serratus anterior that pull the shoulder girdle and thoracic vertebrae anteriorly are thought to be caused by high mileage and the "head-up" freestyle stroke (Ellapen *et al.*, 2013). While the link between shoulder injury and previous shoulder injury was tenuous, 66.67% of athletes who had had previous shoulder injury, were found to have poor shoulder posture (Gradidge *et al.*, 2014).

Decreased external rotation strength relative to internal rotation strength (ER:IR ratio) has been identified in water polo as well as other overhead and throwing populations (Hams, Witchalls and Adams, 2019; Croteau, 2021; Wilk *et al.*, 1990; Bloomfield *et al.*, 1990; Bak and Peter Magnusson, 1997; Batalha *et al.*, 2012; Mota and Ribeiro, 2012; Struyf *et al.*, 2017; Miller *et al.*, 2018; Olivier and Daussin, 2018; Fadilah *et al.*, 2021; Hadžic *et al.*, 2021; Gibson *et al.*, 2022; Johansson *et al.*, 2022). This deficit usually presents as a decrease in the eccentric strength of the external rotators which would influence the shoulders ability to decelerate the arm during follow through and potentially increase the risk of injury risk (Bloomfield *et al.*, 1990; Clarsen *et al.*, 2014; Olivier and Daussin, 2018). In preseason testing of baseball players, this imbalance was found to be a predictor of future injury (Pontillo, Spinelli and Sennett, 2014). Similar results were found in elite and adolescent tennis and volley ball players (Cools, Palmans and Johansson, 2014; Hadžic *et al.*, 2021; Johansson *et al.*, 2022). However, in swimmers with painful shoulders, a generalised decrease in strength due to pain inhibition has been noted, creating an inverse of this relationship (Bak and Peter Magnusson, 1997; Struyf *et al.*, 2017).

Glenohumeral Internal Rotation Deficit (GIRD) is a common adaptation of the glenohumeral joint in overhead athletes (Harput *et al.*, 2016). GIRD has been defined as a loss (>18°- >20°) of internal rotation range of motion in the dominant versus non-dominant arm (Wilk *et al.*, 2011; Keller *et al.*, 2018; Zajac and Tokish, 2020). This side-to-side difference is usually not as apparent in swimmers as it is in unilateral overhead athletes, due to the bilateral nature of the sport. There is also no sudden deceleration of the shoulder joint in swimming as there is in other overhead sports (Struyf *et al.*, 2017).

There have been several inconsistencies found in recent literature on GIRD measurements and so it is important to look at the whole clinical picture before labelling GIRD as being pathologic (Zajac and Tokish, 2020). There were no significant findings (in a meta-analysis and systematic review) associating GIRD with shoulder and elbow injuries in overhead throwing athletes. However, it was determined that there was a trend suggesting a potential association between injuries in overhead athletes and conditions such as GIRD, rotational loss (total range of motion) and ER gain of the dominant limb when compared to the non-dominant limb (Keller *et al.*, 2018). Competitive water polo players were at risk with an even smaller GIRD deficit, with (Isaac *et al.*, 2022) finding a range of <5° to be a risk factor. Tennis players were more at risk of injury if they had decreased dominant glenohumeral internal rotation, rather than GIRD (Kekelekis *et al.*, 2020). An increase in TROM has been found to offer a protective effect in overhead athletes (Keller *et al.*, 2018). However, in sub-elite water polo players, Hams et al., (2019) found that a preseason difference in TROM in the dominant shoulder of ≥ 7.5° was predictive of future injury.

Shoulder range of motion screening during the preseason in youth and adolescent baseball pitchers was found to be a successful tool to identify those who had an increased risk of injury during the season (Shanley *et al.*, 2015; Croteau *et al.*, 2021). Side to side differences of horizontal adduction of 15° or more and an internal rotation range of more than 13° were found to be predictors of injury and should be monitored throughout the season (Shanley *et al.*, 2015; Croteau *et al.*, 2021). On the contrary, a systematic review on overhead sports by Hoppe *et al.*, (2022) explains how in handball players, shoulder internal, external, and TROM was not predictive of acute injuries. Similarly in professional baseball pitchers, shoulder internal and TROM deficits were not related to injury or surgery. However, in pitchers with external rotational ROM deficits, injury risk was increased (Hoppe *et al.*, 2022).

In swimmers, an absolute ER of > 100° or < 93°, increased injury risk (Walker *et al.*, 2016; Pozzi *et al.*, 2019). In another meta-analysis and systematic review looking at preseason screening of shoulder range of motion in overhead athletes, Pozzi *et al.*, (2019) concluded that professional baseball players were at risk of in-season injury if the external rotation of throwing arm wasn't at least 5° greater than the non-throwing arm.

GIRD has been attributed to humeral retroversion and posterior capsular stiffness (posterior capsular thickening and muscular adaptations) (Zajac and Tokish, 2020). While it's possible to modify certain aspects of GIRD, it's important to note that a portion of it is inherently non-modifiable due to its association with humeral retroversion. Therefore, while some factors contributing to GIRD can be addressed and improved through interventions, a component of GIRD remains unalterable, linked to the natural orientation of the humerus bone.

Humeral retroversion is "an acute angle formed by a line connecting the medial and lateral condyles and the line bisecting the humeral head", where a more posteriorly positioned humeral head is called humeral retroversion (Habechian, Lozana and Camargo, 2017). Humeral retroversion is thought to be an advantageous adaptation in throwing sports. Retroversion permits an increase in external rotation which in turn facilitates increased throwing velocity (Roach *et al.*, 2012). Where the anterior shoulder structures may be "protected" by a greater retroversion angle, the posterior structures (rotator cuff and posterior capsule) and required to absorb greater forces during deceleration due to this greater throwing force allowed by the greater ER that is achieved and may cause injury (Greenberg *et al.*, 2015).

The degree of humeral retroversion naturally decreases slowly through childhood, until it reaches its adult value of 25°-30° at age 16. Participation in high frequency throwing sport has been shown to slow down the normal decrease of this retroversion angle and leaves the dominant shoulder with relatively increased retroversion angles (Kay *et al.*, 2018). This was demonstrated in masters baseball players, water polo players and found to occur bilaterally in adolescent competitive swimmers (Whiteley *et al.*, 2010; Habechian, Lozana and Camargo, 2017; Hams *et al.*, 2018). A higher volume of swimming was associated with a higher angle of humeral retroversion (Habechian, Lozana and Camargo, 2017). Humeral retroversion has been found to cause between 10° and 17° of internal rotational loss (Kinsella *et al.*, 2014; Kay *et al.*, 2018). Furthermore, athletes with a history of shoulder injury exhibited a significantly smaller humeral retroversion angle difference between their dominant and non-dominant arms (Kay *et al.*, 2018).

Posterior shoulder stiffness is identified as being one of the most common adaptations seen in the dominant shoulder of the overhead throwing athlete (Cools *et al.*, 2015). Both reduced glenohumeral internal rotation range and horizontal adduction are clinical signs of this stiffness and are attributed to a tight posterior capsule and muscle contracture resulting from micro-trauma of the deceleration phase of repetitive throwing (Cools *et al.*, 2015; Harput *et al.*, 2016; Bakshi and Freehill, 2018; Kay *et al.*, 2018; Isaac *et al.*, 2022). Posterior inferior tightness may lead to a narrowing of the subacromial space, therefore leading to subacromial impingement (Huffman, Tibone and Mcgarry, 2006; Harput *et al.*, 2016). A posterior superior glide of the humeral head in the cocking phase of throwing causes the rotator cuff tendons to be pinched at the posterior-superior glenoid rim, therefore causing internal impingement (Gagey and Boisrenoult, 2004; Bakshi and Freehill, 2018).

There have been some interesting ultrasound findings in elite badminton players, where an increased acromio-humeral distance (AHD) was strongly related to better external rotation strength and supraspinatus tendon thickness (physiological hypertrophy due to load) on the dominant shoulder in injury free players. This may be an indication that prolonged loading and hypertrophy reduces the mechanical stress on the tendon. Therefore, including external rotators in a strength program may reduce injury risk (Schmidt *et al.*, 2021).

The core is a pivotal link in the kinetic chain (Sciascia *et al.*, 2012). Young female swimmers with shoulder pain were found to have weaker core stability than athletes without pain (Struyf *et al.*, 2017; Tate *et al.*, 2017). Force is generated by the lower limbs and is then directed up the kinetic chain, via the hips and trunk, through the scapulohumeral complex, to the arm (Reeser *et al.*, 2010; Sciascia *et al.*, 2012). In land based sports, one or two feet are planted on the ground and thus a stable base is offered. In turn, ground reaction force is generated (Sciascia *et al.*, 2012). This contribution to throwing velocity is lost in water polo players. Core instability in volley ball players was seen more in athletes with shoulder dysfunction, therefore highlighting both the importance of a stable core and an efficient kinetic chain (Reeser *et al.*, 2010). A 20% decrease in power due to kinetic chain dysfunction, led to a need for 34% more velocity to be generated by the shoulder and arm when looking at a tennis serve (Kibler, 1995; Sciascia *et al.*, 2012). This emphasises the significance of water polo players possessing a proficient kinetic chain, characterized by sequencing, stability and strength. This is crucial because they heavily depend on strong leg and core muscles to propel themselves through the water. When the kinetic chain does not operate optimally, it can lead to heightened stress on the shoulder and elbow, elevating the risk of injuries (Girdwood *et al.*, 2021).

The scapulohumeral complex is an integral part of the kinetic chain in the overhead or throwing athlete due to the number of repetitions/revolutions the shoulder is moved in an elevated position (Sciascia *et al.*, 2012). A complete range of movement and so, efficient scapula kinematics should be accompanied by sufficient scapular rotation along three axes. This rotation is necessary to enable the scapula to tilt backward, externally rotate, and upwardly rotate. These actions are vital for ensuring stability and seamless coordination between the arm and shoulder during dynamic movements (Mclaine, Ginn, *et al.*, 2018). Altered scapula kinematics were found in water polo players with shortened pectoralis minor and latissimus dorsi, weak serratus anterior and lower and middle trapezius (Tate *et al.*, 2009; Laudner and Williams, 2013; Mukhtyar, Mitra and Kaur, 2014; Fadilah *et al.*, 2021). It has been suggested that this scapula muscle imbalance may cause scapula dyskinesis, in turn increase glenohumeral contact and, cause rotator cuff impingement (Escamilla and Andrews, 2009; Borstad and Ludewig, 2013; Edmonds and Dengerink, 2014; Fadilah *et al.*, 2021). Scapula dyskinesia was identified as a risk factor for shoulder pain in hand ball, tennis and cricket players but not in high school baseball players (Clarsen *et al.*, 2014; Green *et al.*, 2019; Kekelekis *et al.*, 2020; Gibson *et al.*, 2022).

In elite water polo players with shoulder pain, scapula upward rotation was shown to decrease after an intense practice, and so potentially increase the risk of rotator cuff impingement (Mukhtyar, Mitra and Kaur, 2014). Similarly, changes in upward scapula rotation have been associated with pain and fatigue in swimmers, although this has been associated with athletes who already had impingement symptoms and not in those who had healthy shoulders when tested after a swimming session (Struyf *et al.*, 2017; Mclaine, Ginn, *et al.*, 2018). Additionally, latissimus dorsi stiffness in college age swimmers had moderate to good relationships with increased scapular upward rotation, posterior tilt and decreased internal rotation. If left unaddressed this may lead to injury (Laudner and Williams, 2013).

The SICK scapula is characterised by scapula malposition, inferior medial border prominence, coracoid tenderness and scapula dyskinesis. The scapula moves in a variety and combination of different directions over the rib cage. The normal movement of the scapula is controlled by scapula stabilisers which can easily become imbalanced both with and without injury and this is often seen in the overhead athlete (Edmonds and Dengerink, 2014; Croteau *et al.*, 2021). The stabilisers that have been shown to demonstrate weakness in this situation would be the serratus anterior, infraspinatus, middle and lower trapezius. The stabilisers that are in tension are the levator scapulae, upper trapezius and pectorals (Edmonds and Dengerink, 2014; Croteau *et al.*, 2021).

There is continued debate as to whether athletes display joint laxity due to adaptation, or whether it is innate (Jobe, Kvitne and Giangarra, 1989; Mcmaster, Roberts and Stoddard, 1998; Borsa *et al.*, 2005; Michener *et al.*, 2009). Jobe and Kvitne (1995) hypothesised that competitive swimmers whose shoulders undergo repetitive forceful revolutions may cause gradual stretching of anterior-inferior capsuloligamentous structures which may in turn lead to laxity (Sein *et al.*, 2010). Both Sein *et al.*, (2010) and Borsa *et al.*, (2005) disagreed and found that although glenohumeral joint laxity in swimmers was associated with shoulder pain and impingement pain, that there was no correlation between swimming load and shoulder laxity. Compared with age matched controls, swimmers as a group did not have significantly more shoulder laxity (Sein *et al.*, 2010). Glenohumeral joint laxity in combination with scapular dyskinesis, strength and control deficits and training load over a season, may however predispose the athlete to shoulder injury (Lippincott, 2018).

An “injury cascade” has been described, where a number of intrinsic factors, when combined, may have a summative effect on the kinetic chain and result in chronic and vigorous overload (Uhl and Kibler, 2009; Edmonds and Dengerink, 2014). Cools *et al.*, (2015) also share the notion that a combination of factors at pre-season testing would assist in predicting future overuse shoulder pain.

Adolescents are at risk of sustaining a new injury if they do not get enough sleep or have irregular sleep patterns (Rosen *et al.*, 2016; Fox *et al.*, 2019). “Enough” sleep was classified as 8 hours a night during week days. Injury risk decreased significantly with increased hours of sleep (Rosen *et al.*, 2016; Fox *et al.*, 2019).

Due to discrepancies in throwing and overhead techniques of various sporting codes and poor quality evidence, a consensus on definitive risk factors of shoulder injury has not yet been reached (Cools *et al.*, 2015; Asker *et al.*, 2018). There are a number of factors that are highlighted in the research across the board for overhead sports, as well as in the limited available water polo research. The most prevalent intrinsic risk factors identified are GIRD, decreased TROM, decreased glenohumeral ER strength and scapula dyskinesis (Reeser *et al.*, 2010; Laudner and Williams, 2013; Harput *et al.*, 2016; Shitara *et al.*, 2017; Miller *et al.*, 2018; Hams *et al.*, 2019; Green *et al.*, 2019; Hams, Witchalls and Adams, 2019; Pozzi *et al.*, 2019; Isaac *et al.*, 2022).

Although there isn’t one single “shoulder risk screening tool”, there are various individual effective and validated tests for identifying the above mentioned risk factors in overhead sports. These could be used to formulate a screening tool for water polo injuries in the future.

2.5.2 Extrinsic risk factors

In recent injury research there has been an increasing emphasis on exploring external or environmental factors that are believed to play a significant role in injury occurrence within water polo and other overhead sports. These include factors such as overuse (from throwing, pitching and swimming) and early sports specialisation (Webster, Morris and Galna, 2009; Ellapen *et al.*, 2013; Gradidge *et al.*, 2014; Drew and Finch, 2016; Asker *et al.*, 2018; Miller *et al.*, 2018; Hams, Evans, Waddington, *et al.*, 2019; Zaremski, Zeppieri Jr and Tripp, 2019).

Shoulder injury in water polo has been attributed largely to "overuse" from the accumulative demands of swimming, throwing and defending (Webster, Morris and Galna, 2009; Bliven *et al.*, 2021; Croteau *et al.*, 2021; Orringer and Pandya, 2021). Most shoulder injuries are caused by overuse or minor trauma as opposed to traumatic injury, especially in the adolescent population (Croteau *et al.*, 2021; Orringer and Pandya, 2021). The physical demand on the upper limbs is greater due to the added weight of the ball and their body being immersed in water, which increases the risk of musculoskeletal pain or injury (Webster, Morris and Galna, 2009). A higher level of sport and increased volume of play also increased the relative risk of injury in tennis and volleyball players (Cools *et al.*, 2015).

A high number of training hours per week in baseball pitchers and catchers and youth handball players put them at higher risk for injury (Zaremski and Krabak, 2012; Asker *et al.*, 2018; J. Zaremski, Zeppieri and Tripp, 2019; Hoppe *et al.*, 2022). The throwing factors that contribute to the training hours include the volume of pitches thrown, the number of innings pitched and the use of long toss throws (Lyman *et al.*, 2002; Zaremski and Krabak, 2012). The American Sports Medicine Institute, USA baseball and baseball Canada, have put pitching restrictions in place for both adult and little league baseball (Zaremski and Krabak, 2012). Acute increases in workload per day or per week and overall workload were found to be risk factors for elite cricket players (Saw *et al.*, 2011). Bliven *et al.*, (2021) found limited or conflicting evidence in a systematic review looking at risk factors for injury adolescent overhead sports. One finding was that parents of baseball pitchers, who followed pitching load guidelines, were significantly less likely to have an athlete with a shoulder injury. Fadilah *et al.*, (2021) suggest that in overhead sports, fatigue might affect muscle strength balance and thus shoulder joint stabilization and therefore increase injury risk.

More specifically to water polo, shoulder soreness in female national level players, increased with an increase in the number of overhead shots taken at goal during training and this was further aggravated with shorter rest periods between shots (Wheeler *et al.*, 2012). There has been little correlation between demographics and training variables and therefore surmised that shooting/throwing loads were better predictors of injury in water polo players of different levels (Webster, Morris and Galna, 2009; Croteau *et al.*, 2021; Girdwood *et al.*, 2021). Additionally, Bliven *et al.*, (2021) did find that hours of training per week affected injury risk.

Elite swimmers had a significant link to training load and repetitive mechanical loading. Swimmers, who swam for 15 hours or more per week, swam 35km or more per week or swam at a high level, were more likely to develop supraspinatus tendinopathy and had confirmed symptomatic supraspinatus tendinopathy (thickened tendon) on MRI (Sein *et al.*, 2010). Competitive swimmers can log 9-12km per day and be training 6-11 times per week. Documenting load is exceptionally important as these high training volumes have often been associated with injury (Struyf *et al.*, 2017). In a conflicting study, there were no meaningful associations found between shoulder pain and years of competitive swimming, training frequency, training duration or weekly volume (Sein *et al.*, 2010). Furthermore, there were no significant differences between shoulder pain and playing an overhead sport in addition to swimming. Sprint swimmers and swimmers that did individual medley (70%), butterfly (56.5%) or freestyle (54.7%), had higher risk of injury (Sein *et al.*, 2010). Water polo carries the risk of throwing that has been frequently identified in other overhead throwing sports on land but is further increased by the swimming training done for fitness and the adapted stroke which provides an inherent risk for impingement (Webster, Morris and Galna, 2009; Klein *et al.*, 2014; Stromberg, 2017; Miller *et al.*, 2018).

Further, Fleisig and Andrews, (2012) found that youth baseball pitchers from warmer climates were able to play baseball for more months of the year than pitchers from colder climates. This resulted in a greater dominant shoulder range of motion in athletes from warmer climates. They concluded that a greater volume of pitching (extrinsic risk factor), may result in a greater shoulder range of motion and strength adaptations (intrinsic risk factor), and thereby make the athlete more susceptible to injury. Therefore it is important to monitoring training load and the athlete's response to it, to ensure optimal performance and the prevention of injuries and illness (Drew and Finch, 2016).

Early specialisation of adolescent baseball players has been discouraged due to the high prevalence of injuries attributed to high throwing load (J. Zaremski, Zeppieri and Tripp, 2019). Athletes were encouraged to play multiple sports, play a throwing sport for no more than eight months of the year and have at least two months of consecutive rest from throwing to decrease the load on a developing shoulder (J. Zaremski, Zeppieri and Tripp, 2019). Professional baseball players who specialised early, had significantly more severe injuries than those who did not (Wilhelm, Choi and Deitch, 2017). Bell *et al.*, (2018), found a linear relationship between the risk of overuse injury and level of specialisation. Not only is the risk of overuse injury increased, but the adolescent may face psychological fatigue and burnout (Popkin, Charles, Bayomy and Ahmad, 2019).

Although there is minimal research on the risk factors for injury in water polo, increased training load and poor recovery protocols, combined with one or more of the identified intrinsic risk factors, will further increase the water polo athletes' injury risk. This highlights the need for continuous injury screening, maintenance, rehabilitation after injury and load monitoring in water polo (Webster, Morris and Galna, 2009; Klein *et al.*, 2014; Stromberg, 2017; Miller *et al.*, 2018).

2.6 Performance

2.6.1 Throwing performance

Throwing speed (TS) and throwing accuracy (TA) both contribute to overall throwing performance (TP). These performance outcomes are further associated with musculoskeletal, biomechanical, technique or skill and cognitive (motor learning and visual) variables (Freeston and Rooney, 2014; Raeder, Fernandez-Fernandez and Ferrauti, 2015). TS has been much more widely researched in multiple sports in the literature in comparison due to the more complex nature of the factors involved with TA (Ahmed, Brown and Gray, 2020).

Previous findings in overhead sports (baseball in particular) have been presumed to be relevant and applicable to athletes participating in all overhead sports. However, Dutton *et al.*, (2019) demonstrated that cricket players had a unique musculoskeletal profile and that the cricketer's shoulder was not a typical throwers shoulder and this highlighted the need for research of this nature to be conducted in other overhead sports. Moreover, the unique profile of water polo players should be investigated fully, due to the fact that submersion in water requires power to be generated from an unstable base and the rate of the throwing may occur in quick succession and with little rest (Webster, Morris and Galna, 2009; Miller *et al.*, 2018).

2.6.1.1 Variables associated with throwing speed

There are many varying musculoskeletal factors associated with TS. These factors include modifiable (strength, flexibility, endurance) and non-modifiable (limb length and height) factors and must take the whole body and kinetic chain into consideration for efficient throwing (Chu *et al.*, 2016). Although there are apparent biomechanical similarities in overhead throwing across different sports, the understanding of how specific musculoskeletal factors contribute to overhead throwing in various sports remains limited.

In female elite water polo populations, maximal hand grip strength (Ferragut *et al.*, 2011), and shoulder internal and external rotation strength and power (Platanou and Veramenti, 2011) have all been correlated with TS. General upper body and shoulder strength was also correlated with TS in youth water polo players, cricket and handball players (Freeston *et al.*, 2016; Ortega-becerra, Pareja-blanco and Jiménez-reyes, 2017; Keiner *et al.*, 2018; Djanis, 2021; Ramalheira *et al.*, 2022).

Increased, adaptive changes to shoulder ER have been previously assumed to be advantageous and offer a bigger wind up during the cocking phase of pitching and throwing in both baseball and cricket. There have been conflicting studies on baseball pitching speed and increased shoulder ER ROM, so the evidence relating to TS remains inconclusive (Keller *et al.*, 2018; Reinold *et al.*, 2018). Stride length, maximum shoulder ER and IR, trunk flexion at ball release were predictors of TS in cricket players (Djanis, 2021).

In-water proprioceptive acuity is an important determinant of TS in state level (male and female) water polo players. This was tested using a land based and in-water AMEDA (active movement extent discrimination assessment) device (Hams *et al.*, 2019). Core stability to correlated with TS in collegiate overhead throwing athletes (Nuhmani, 2022).

Lower limb strength and power were also found to be predictors of TS in youth and female water polo and handball populations (McCluskey *et al.*, 2010; Ortega-becerra, Pareja-blanco and Jiménez-reyes, 2017; Keiner *et al.*, 2018). In cricket, non-dominant hip abduction strength, isometric mid-thigh pull, lateral to medial jump and braking ground reaction force were also predictors of TS (Ahmed, Brown and Gray, 2020; Djanis, 2021).

Conflicting results for anthropometric variables have been found in elite female water polo populations with only two of the three studies finding a correlation between anthropometric variables and TS (McCluskey *et al.*, 2010; Ferragut *et al.*, 2011; Platanou and Veramenti, 2011). Anthropometric variables and upper body strength and power were associated with TS in a youth water polo population (Ramalheira *et al.*, 2022).

2.6.1.2 Variables associated with throwing accuracy

Accuracy is a complex concept that combines musculoskeletal factors with cognitive, sensory motor and proprioceptive variables for efficient throwing, serving, pitching or bowling in overhead sport (Hams *et al.*, 2019). Musculoskeletal variables have been found to differ between sports and even different levels of play and experience in cricket players (Ahmed, Brown and Gray, 2020).

Specific musculoskeletal variables associated with TA in water polo have not yet been assessed. Pectoralis minor length correlated with TA in cricket players, while shoulder stability/function (KJOC) did not (Ahmed, Brown and Gray, 2020). Core stability and upper extremity stability and proprioception has also been associated with better TA and overall TP in overhead (land based) throwing athletes and baseball pitchers but not in tennis players (Fernandez-fernandez *et al.*, 2013; Lust *et al.*, 2016; Jha *et al.*, 2022; Nuhmani, 2022).

A concept of speed-accuracy trade-off (SATO) has also been discussed in the literature for overhead sport such as baseball, cricket and water polo. Accuracy was found to decline when athletes threw at 70% and above of their maximum throwing speed, highlighting the importance of having optimal function of TS and TA in order to reduce the SATO and score points or goals (Freeston and Rooney, 2014; Freeston *et al.*, 2014).

Further future sport specific research is necessary, in order to determine which factors are associated with TA in different sports.

2.6.2 Swimming performance

Sport specific positioning whilst strength training may be important in the efficacy of strength and rehabilitation programming in sports like swimming and water polo. Strength and scapular kinematic variables were unchanged in collegiate swimmers who selected their own Theraband resistance and did their exercises in standing (Hibberd *et al.*, 2012). Another group of elite swimmers did their exercises with body weight in a functional, swimming specific prone position and they were found to have improvements in strength, pain, forward head posture and dysfunction (Lynch *et al.*, 2010). The intervention group reported a decreased incidence of shoulder pain which demonstrates a protective benefit of an exercise programme like this one despite a lack of measured changes in musculoskeletal outcome measures (Lynch *et al.*, 2010).

Both dry land and in water resistance or strength training programs have demonstrated significant improvements in performance in swimmers (Guo, Soh and Zakaria, 2022). A thorough systematic review examined how exercise routines impact the risk factors related to swimmers' shoulder. The review found that significant improvements in risk factors occurred when participants engaged in programs lasting at least six weeks, with exercise sessions held 2-3 times per week. On average, participants performed 10-15 repetitions of each exercise, gradually increasing the intensity over the weeks. The most effective programs for enhancing both strength and endurance utilized open kinetic chain exercises on land and consisted of five or fewer exercises (Tavares, Dias and Carvalho, 2022).

Given the amount, quality and relevance of the available literature on water polo and overhead sports, it is difficult to draw substantial conclusions from the results due to a wide variety of methodology used across the studies of various sporting codes. This highlights the need for more extensive injury, prehabilitation and rehabilitation research in water polo and other overhead studies in order for comparisons to be made and reliable reviews to be conducted.

An "ideal" exercise intervention, based on the identified risk factors of water polo and overhead athlete, is multi factorial. A progressive program, starting with control and stability and then progressing to more functional and explosive exercises should be implemented. Strength of the legs and core should be equally important to that of the shoulder. Based on the demands of water polo, strengthening should be done in a functional position, with elements of rotation involved. The external rotators of the shoulder should be strengthened, with focus on eccentric strength, in a functional throwing capacity in order to be able to resist the demands of the deceleration phase of throwing. The periscapular muscles need to be strengthened and balanced in order to have good scapular kinematics with appropriate endurance and fatigue tolerance. The latissimusdorsi and posterior capsule should be stretched if it is found to be tight and therefore contributing to a glenohumeral internal rotation deficit (Bloomfield *et al.*, 1990; Fernandez-fernandez *et al.*, 2013; Palmer *et al.*, 2015; Raeder, Fernandez-Fernandez and Ferrauti, 2015; Lust *et al.*, 2016; Reinold *et al.*, 2018; Sakata *et al.*, 2019; Turgut *et al.*, 2019; Oranchuk, Ecsedy and Robinson, 2021; Jha *et al.*, 2022).

2.7 Rehabilitation and Interventions

The glenohumeral joint is an extremely mobile, incongruent, ball and socket joint. The osseous stability is poor, however, the static and dynamic stabilisers provide effective functional stability (Chang and Polster, 2016). Functional stability is a product of static stabilisers (joint capsule, bony anatomy and labrum), dynamic stabilisers (rotator cuff muscles, long head of the biceps tendon and scapulothoracic muscles) and an optimal sensorimotor system (Wickham *et al.*, 2010; Vogler *et al.*, 2019).The latissumus dorsi, pectoralis major and teres major are the main "torque producers" or movers of the shoulder joint (Boettcher, Cathers and Ginn, 2010; Wickham *et al.*, 2010).

The majority of data concerning intervention and conditioning programs predominantly stems from baseball pitching (Lust *et al.*, 2016; Reinold *et al.*, 2018; Sakata *et al.*, 2019; Melugin *et al.*, 2021; Oranchuk, Ecsedy and Robinson, 2021) while a smaller proportion comes from other sports such as cricket, handball, volleyball, and a few other overhead sports (Freeston *et al.*, 2016; Djanis, 2021). Limited high-quality evidence exists regarding water polo.

2.7.1 The effect of exercises on risk factors

The aim of exercise intervention studies are to improve strength and stability of the rotator cuff muscles, improve or maintain scapular kinematics and restore balance or strength of muscle groups along the whole kinetic chain. The goals of an intervention programme are typically aimed at lowering injury risk and/or improving throwing performance parameters. These programmes may include previously identified risk factors in the overhead athlete such as poor shoulder and scapula proprioception and stability, decreased glenohumeral ER strength and posterior shoulder tightness (Reeser *et al.*, 2010; Laudner and Williams, 2013; Harput *et al.*, 2016; Shitara *et al.*, 2017; Miller *et al.*, 2018; Hams *et al.*, 2019; Green *et al.*, 2019; Hams, Witchalls and Adams, 2019; Pozzi *et al.*, 2019; Isaac *et al.*, 2022).

There is however limited good quality evidence on the effectiveness of injury prevention programs for overhead sports (Asker *et al.*, 2018) and even less on water polo. In a systematic review that looked at exercise prescription for overhead athletes, it was concluded that due to various differences in definition, lack of clarity on exercises used or poor quality research, there is no gold standard exercise protocol yet (Wright *et al.*, 2017).

While injury prevention programs have been recommended for overhead athletes, only just over half of athletes taking part in the aquatics World Championships in 2017, actually took part in the recommended preventative exercises (Mountjoy and Miller, 2019). Higher ranked countries were found to include these exercises more regularly than lower ranked countries, but also had better access to the greater medical team (sports scientist, mental health support and nutritionist) (Mountjoy and Miller, 2019).

Exercise interventions for injury prevention and/or performance in overhead sports ranged in duration from four weeks to 12 months, with an average time of 6-8 weeks. Strength and stretching protocols also varied and the length of time of the intervention didn't appear to correlate to efficacy of the intervention although the minimum time for a program to show efficacy was four weeks. This is summarised in Table 2-1 below:

Table 2-1 Intervention programs in overhead sports

Author	Sport	Age group	Type of exercises	Format	Findings and Result
Bloomfield et al., (1990)	Water Polo	Elite Junior	Nautilus weights station Brachialis, Deltoid Pectoralis minor, Latissimus dorsi, biceps & triceps brachii, teres major, trapezius	8 weeks 3 sets of 15 3 x per week	No change in throwing velocity Significant strength increases
De Villarreal et al., (2014)	Water Polo	Elite Male	Dry land- Bench press, squat, pull-up, split squat Power clean, abdominal exercises, med ball exercises MB single arm throw, wall throw Water based - Banded eggbeater back and forwards Back and front swim with band Lateral jumps, post to post, MB vertical jump	6 weeks 3 x per week 60 minutes	Significant improvements in in-water boost, counter movement jump, swimming agility, and maximal dynamic strength tests in both groups. Benefit in including dry-land and in-water high intensity training
De Villarreal et al., (2015)	Water Polo	Elite	Added plyometric component - burpees, med ball back toss No difference between the 3 training groups	6 weeks 3 x per week	Improvement with a combination of in-water strengthening and dryland plyometric training as well as power training (bench press, squats, pull-ups, etc.) on similar water polo-specific parameters
Batalha *et al.*, (2014)	Swimming	Adolescent Male	Banded ER Banded ABD Banded shoulder press	16 weeks 3 x per week 3 sets (2 x 20, then last one until exhaustion)	Increase ER peak torque Increase ER:IR ratio
Hibberd *et al.*, (2012)	Swimming	Collegiate	Banded Flexion, extension, ER and IR at 90° Low rows, Throwing acceleration Throwing deceleration Y, T, W with band Pectoralis minor and sleeper stretch	6 weeks 3 x per week Stretch - 2 x 30 second hold Strength - 2 sets of 15	Program was not effective in altering strength and scapular kinematic variable
Lynch *et al.*, (2010)	Swimming	Elite	Y to W L to Y Scapula Protraction Pectoralis stretch Chin tucks	8 weeks 3 x per week 3 sets of 10	Decrease in forward head and rounded shoulder posture Increase in shoulder strength Decrease in perceived pain Improvement in dysfunction

Tessaro *et al.*, (2017)	Swimming	Adolescent	Dryland warm-up	12 months Average of 20 minutes	Dry land warm-up >5 times per week appeared to protect swimmers from pain Dry land warm-up >10 minutes seems to cause shoulder pain A single physical training duration <45 minutes seems to be associated with pain
Chepeha *et al.*, (2018)	Overhead	University	Sleeper stretch	8 weeks Once daily 5 Repetitions Hold each stretch for 2 minutes	IR deficit ≥15˚ significantly increased IR and HAd ROM
Maenhout *et al.*, (2012)	Overhead	Young Adult	Sleeper stretch for posterior capsule	6 weeks 3 repetitions for 30 seconds Once a day	Increased the acromiohumeral distance in the dominant shoulder
McClure *et al.*, (2007)	Non-Specific	University Mixed	Posterior capsule stretch	4 Weeks	Cross body stretch was significantly more effective in improving IR than the Sleeper stretch
Rogol, Ernst and Perrin, (1998)	Military Cadets	Young Adult	OKC - 3 sets of 15 supine dumbbell press CKC - 3 Sets of 15 push ups	6 Weeks 3 x per week	The OKC and CKC groups decreased in reposition sense error scores in comparison with the control group No difference was found between the training groups
Turgut, Duzgun and Baltaci, (2017)	Non specific	University	Pectoralis minor stretch Cross body stretch Levator scapula stretch Latissimus dorsi stretch	6 weeks Daily 3 sets of 5 repetitions 30 seconds holds	Increased flexibility Decrease pain and disability Recommended for patients with SIS symptoms
Andersson *et al.*, (2017)	Handball	Elite	OSTRC program Sleeper stretch Eccentric ER Scapula Control Kinetic chain walkout Thoracic rotations	7 months (1 season) 3 x per week 10 minute warm up	28% reduction of injuries in intervention group

Fredriksen *et al.*, (2020)	Handball	Adolescent	Sleeper stretch Eccentric ER Scapula Control Kinetic chain walkout Thoracic rotations	18 weeks 3 x per week as a warm up	No effect in ER strength or IR ROM
Raeder, Fernandez-Fernandez and Ferrauti, (2015)	Handball	Young Adult Females	Medicine ball training 2-arm overhead diagonal throws 2-arm side rotational throws single-hand shot put throws Plyometric	6 Weeks 3 x per week	Improved throwing velocity Improved isokinetic strength of IR and ER No improvement in precision
Fernandez-fernandez *et al.*, (2013)	Tennis	Adolescent	3 sets of 20 reps - crunch, reverse crunch etc 2 sets of 20 sec holds -plank, side plank 2 sets of 20 reps for the 9 Theraband exercises	6 weeks 3 x per week 60-70 mins	Marked improvement in serving velocity Accuracy unchanged
Niederbracht *et al.*, (2008)	Tennis	Collegiate Female	External Rotation at 90° Scaption Chest Press External Shoulder Rotation (Rubber tubing) Seated Row 5 rep max	5 weeks 5 exercises 4 x per week 3 sets of 15	Significant increase in ER eccentric work capacity
Lust *et al.*, (2016)	Baseball	University	OKC, CKC and/or core-stability exercise Sitting scaption with the arm in 30° of horizontal abduction and internal rotation Prone lying horizontal abduction with the arm externally rotated Prone lying single-arm rowing Supine-lying barbell bench press	6 weeks 3 x per week 30-45 minute sessions	Improvements in all groups No significant difference in improvements between groups Improvements ranged from 1.36% and 140% Improvement in accuracy
Pellegrini *et al.*, (2016)	Baseball	Collegiate	Post capsule stretches	4 weeks 3 x per week	Posterior capsule and cuff stretching can help improve and restore normal scapula kinematics

Sakata *et al.*, (2019)	Baseball	Adolescent	Stretching for elbow, shoulder and hip - 1 set of 10 sec holds Dynamic mobility for thorax and scapula - 1 set of 10 ex each Lower extremity balance	12 months period Strength and stretching at least once a week for 10 mins 1 set of 10 repetitions	Injury risk (shoulder and elbow) of the intervention group was 48.5% lower than the control group Improved previously identified anatomical risk factors Improved throwing velocity
Shitara *et al.*, (2017)	Baseball	Adolescent	Sleeper stretch Control group did strength (prone ER) and stretching exercises	One season 3 Sets of 20 Repetitions Sleeper stretch - 5 Repetitions of 60 seconds	Self-stretching reduced injuries significantly 3 times later onset of injury in the season No difference between the groups
Turgut *et al.*, (2019)	Volleyball	Youth Female	Elastic band shoulder ER at 0 Elastic band shoulder ER at 90/90 Overhead throw using a 2-kg medicine ball 90/90 ER side-throw Deceleration throw Volleyball serve	12 weeks 3 x per week	Improvement in explosive power and strength and endurance Recommend plyometric exercises be used as both performance enhancing and injury prevention Improved velocity No improvement in reaction time

ER: external rotation, IR: internal rotation, ROM: range of motion, HAd: horizontal adduction, OKC: open kinetic chain, CKC: closed kinetic chain

Various types of exercise and methods have been trialled. Two studies compared open kinetic chain and closed kinetic chain exercises for shoulder proprioception and joint reposition sense (Rogol, Ernst and Perrin, 1998; Lust *et al.*, 2016). Both groups in both programs improved and it appears that both open and closed chain exercises are effective in improving proprioception and joint reposition sense.

There has been a large focus on strengthening shoulder ER and reducing the ER:IR imbalances in throwing/overhead athletes. Three of the five reviewed studies aimed at improving ER strength were effective in doing so. (Niederbracht *et al.*, 2008; Batalha *et al.*, 2014; Raeder, Fernandez-Fernandez and Ferrauti, 2015). Two of the research investigations incorporated banded workouts, while one emphasised plyometric exercises. These programs varied in duration from 5-16 weeks and were carried out 3 to 4 times weekly. The other two programs had a strength and mobility focus (similar exercises) were ineffective for improving external rotation strength (Hibberd *et al.*, 2012; Fredriksen *et al.*, 2020). The programs were carried out for 6 and 18 weeks and completed 3 times a week Hibberd *et al.*, (2012) suggested that a limitation to their study was that they allowed participants to self-select resistance of bands which may not have offered sufficient resistance for strength gains and some participants appeared to have shoulder pain.

Interventions that had a focus on posterior capsular stretch with either the sleeper stretch or cross body adduction stretch, were successful in either improving glenohumeral internal rotation or GIRD, maintaining or restoring scapular kinematics and reducing pain or injury risk (McClure *et al.*, 2007; Maenhout *et al.*, 2012; Pellegrini *et al.*, 2016; Shitara *et al.*, 2017; Turgut *et al.*, 2017; Chepeha *et al.*, 2018; Sakata *et al.*, 2019). A comparison of the sleeper stretch and cross body stretch found the cross body stretch was significantly more effective in improving IR (McClure *et al.*, 2007). The stretches were all done daily for 30 seconds to 2 minutes for a period of 4-8 weeks.

Although the value of kinetic chain strength and flexibility is well accepted, few studies have evaluated the inclusion of these exercises (Ellenbecker and Aoki, 2020). Of all the reviewed exercise protocols, only two included lower limb strength (Andersson *et al.*, 2017; Fredriksen *et al.*, 2020) and one included lower limb balance training (Sakata *et al.*, 2019). There is therefore a huge gap in the research to include lower limb and kinetic chain factors into future research.

An "ideal" exercise intervention, based on the identified risk factors of water polo and overhead athlete, is multi factorial. A progressive program, starting with control and stability and then progressing to more functional and explosive exercises should be implemented. Strength of the legs and core should be addressed in overhead athletes with the aim of offloading the shoulder and increasing throwing performance (Ellenbecker and Aoki, 2020). Based on the demands of water polo, strengthening should be done in a functional position, with elements of trunk/spine rotation involved. The external rotators of the shoulder should be strengthened, with focus on eccentric strength, in a functional throwing capacity in order to be able to resist the demands of the deceleration phase of throwing. The periscapular muscles need to be strengthened and balanced in order to have good scapular kinematics with appropriate endurance and fatigue tolerance. The latissimus dorsi and posterior capsule should be stretched if it is found to be tight and therefore contributing to a glenohumeral internal rotation deficit.

2.7.2 The effect of exercises on throwing performance

There have been varied results for studies that aimed to improve TP parameters. A shoulder focussed strength program in male junior elite water polo players using a fixed weights station, showed good improvements in shoulder strength, but failed to show any effect on TS (Bloomfield *et al.*, 1990). It was however determined that athletes who were bigger and stronger (lean body mass, height, bi-acromial width and upper limb length), threw with higher velocity in both the intervention and control groups. They proposed that at this elite level, strength variables are already optimal, with sequencing of throw and non-modifiable factors (eg. limb length) being responsible for the athletes throwing proficiency. Treading endurance and leg strength was related to jump height and in turn TS in elite male water polo players. In the same study, non-dominant abdominal strength and both pectoral muscles were also correlated with superior TS (Zinner *et al.*, 2015). Maximal hand grip strength (Ferragut *et al.*, 2011), lower limb strength and power (McCluskey *et al.*, 2010) and shoulder internal and external rotation strength and power (Platanou and Veramenti, 2011) have all been correlated with TS in these female water polo populations.

Previous studies have demonstrated that athletes in water polo and handball can enhance their throwing performance (TP) by improving the strength and stability of their shoulder complex, trunk (core), and lower limbs (McCluskey *et al.*, 2010; Ferragut *et al.*, 2011; Platanou and Veramenti, 2011; Ortega-becerra, Pareja-blanco and Jiménez-reyes, 2017; Noronha *et al.*, 2022). A notable example involves a cohort of college athletes engaged in a core strength training program, which yielded remarkable improvements in TP. This underscores the vital role of a robust core and a stable foundation in enhancing an athlete's throwing abilities (Jha *et al.*, 2022).

Drawing conclusions and comparisons from protocols is difficult due to the variation and combination in methodology. Protocols which achieved improvements in TS or pitching speed included combinations of different modes of exercise including specific shoulder exercises, plyometric exercises, various stretches for the shoulder and elbow, core and trunk stability and whole body strength exercises. Programs used different equipment including bands, dumbbells, barbells, medicine balls, cable weights stations and weighted balls (baseballs) (Bloomfield *et al.*, 1990; Fernandez-fernandez *et al.*, 2013; Palmer *et al.*, 2015; Raeder, Fernandez-Fernandez and Ferrauti, 2015; Lust *et al.*, 2016; Reinold *et al.*, 2018; Sakata *et al.*, 2019; Turgut *et al.*, 2019; Oranchuk, Ecsedy and Robinson, 2021; Jha *et al.*, 2022).

Banded shoulder specific exercises in softball players were effective in improving TS by a meaningful 2.6% in a collegiate population. The study involved two groups; shoulder specific banded exercises and traditional/general gym based upper body weighted exercises. Training sessions were carried out 3 times a week for eight weeks, with four exercises being used in each session. Exercises were progressed weekly (Oranchuk, Ecsedy and Robinson, 2021). This highlights the effectiveness and value of banded exercises in conditioning and rehabilitation. Bands can be easily transported, don’t take up much space and are cost effective.

TS and injury risk (48.5% lower in intervention group) was improved in youth baseball players who did a 12 month program of short (10 second stretches for 10 repetitions) as long as this was done at least once a week for 10 minutes (Sakata *et al.*, 2019). The program consisted of stretching for the elbow, shoulder and hip, dynamic mobility for the thorax and scapula and lower extremity balance exercises. The minimal time and simplicity required should assist in increasing compliance in a youth population.

There was an improvement in TA, core strength and proprioception in university aged baseball pitchers with both open and closed chain exercises (Lust *et al.*, 2016). Exercises included full body weighted (body weight, dumbbell and barbell) exercises, core and plyometric components. The sessions were conducted three times a week for six weeks. Both groups improved, with no significant differences between the groups, indicating that open and closed chain exercises, with or without core exercises is effective in this population.

Weighted balls have been used for conditioning and strength purposes in sport (Palmer *et al.*, 2015; Raeder, Fernandez-Fernandez and Ferrauti, 2015; Reinold *et al.*, 2018; Sakata *et al.*, 2019). Reinold *et al.*, (2018) used weighted baseballs to increase TS in a small study of adolescent pitchers. Even though there were improvements in strength and pitching speed, one should note that it was found to increase passive shoulder ER and increased injury risk in the intervention group by 24%. Further research is needed to assess whether the potential risk of injury of this mode of intervention is worth any increments in performance.

Rather than exclusively concentrating on isolated muscles and specific joint ranges, the prevailing approach in existing literature frequently involves evaluating complete muscle groupings or anatomical regions (Palmer *et al.*, 2015; Raeder, Fernandez-Fernandez and Ferrauti, 2015; Reinold *et al.*, 2018; Sakata *et al.*, 2019; Jha *et al.*, 2022). This approach hinders the ability to discern the precise effectiveness of different components (potentially all) of the intervention program.

2.7.3 The effect of exercises on swimming performance

There has been debate as to whether a dry-land program is beneficial for a water-based sport such as water polo. Based on swimming sprint performance alone, there has been research to show improvements of 1.3%-4.4% (De Villarreal *et al.*, 2014, 2015). De Villarreal *et al.*, (2014), (2015) found that there is benefit in including a combination of both dry-land (power and plyometric) and in-water training sessions in order to achieve full performance benefits.

2.8 Conclusion

Water polo is a unique, fast paced and physically demanding sport that comprises of swimming, treading and throwing. The incidence and prevalence of shoulder injuries in water polo is high across the span of all age groups and levels of play. Nevertheless, there is a lack of evidence on the risk factors associated with the aetiology of these shoulder injuries. Most of the shoulder injuries that are seen in water polo appear to be overuse injuries, rather than acute trauma. Various sports have seen effective exercise interventions have a great benefit to athletes, with decreased injury rates and general increase in the longevity of the athletes sporting career. An effective exercise intervention would aim to address the identified risk factors to decrease the likelihood of injury. There is limited evidence for the impact of exercise intervention programmes on throwing performance in water polo.

Chapter 3
Can musculoskeletal variables predict throwing performance in male adolescent water polo players in South Africa?

3.1 Abstract

Objectives: The majority of throwing performance data comes from baseball pitching, with less from sports like cricket and handball, and limited high-quality evidence for water polo, a sport with distinctive biomechanical challenges due to its unique requirements. This study aims to investigate the relationship between musculoskeletal variables and throwing performance (TP); (throwing speed: TS and throwing accuracy: TA) in adolescent male water polo players.

Design: Cross sectional investigation

Methods: 43 Adolescent (high school), male water polo athletes were tested using a battery of 15 upper limb musculoskeletal tests (strength, range of motion, scapula stability, pain). Throwing performance was evaluated in the pool by testing TS and TA.

Results: Four variables accounted for 64% of the variance in the throwing speed test. The average speed increased with each year of age (14 Average: 50.56km/h, 15 Average: 59.4km/h, 16 Average: 59.9km/h, 17 Average: 60.5km/h) ($p< 0.05$). For every 1° increase in posterior capsule range there was a 0.30km/h increase in throwing speed (95% CI: 0.06-0.54) ($p<0.05$). For every 1N increase in glenohumeral internal rotation strength at 90° abduction there was a 0.04km/h increase in TS (95% CI: 0.00-0.08) ($p< 0.05$). For every 1cm increase in pectoralis minor muscle length there was a 1.2km/h increase in TS (95% CI: 0.11-2.42) ($p< 0.05$). The CKCUEST ($p < 0.05$) correlated with TA, with 1 point increase giving a 0.01 improvement in accuracy score (95%CI: -0.003-0.002).

Conclusion: A number of shoulder musculoskeletal variables influence throwing performance in the adolescent water polo population and may be targeted in future intervention studies to influence throwing performance.

Keywords: Throwing performance, water polo, musculoskeletal, throwing speed, throwing accuracy.

3.2.1 Introduction

Water polo is a physically challenging sport and the demands placed on this overhead athlete differ from other sports. In particular, due to the aquatic nature of the game, these athletes do not have a stable base to initiate the kinetic chain required for an effective throw. Other physical components of the game include head-up swimming, treading, overhead throwing and shooting. This combination of activities place unique biomechanical stressors on these athletes, not seen in other throwing sports (Webster, Morris and Galna, 2009; Miller *et al.*, 2018).

There was a rule change in water polo in 2005 which reduced the offensive possession (attack) to thirty seconds from thirty five seconds. This in turn resulted in a faster game and increased throwing and shooting frequency. Furthermore, this exposed a need to identify specific musculoskeletal factors for both TP enhancements and possible injury prevention (Miller *et al.*, 2018).

The majority of data concerning TP predominantly stems from baseball pitching (Lust *et al.*, 2016; Reinold *et al.*, 2018; Sakata *et al.*, 2019; Melugin *et al.*, 2021; Oranchuk, Ecsedy and Robinson, 2021), while a smaller proportion comes from other sports such as cricket, handball, volleyball, and a few other overhead sports (Freeston *et al.*, 2016; Ahmed, Brown and Gray, 2020; Djanis, 2021). Limited high-quality evidence exists regarding water polo.

TS and TA both contribute to overall TP. These performance outcomes are further associated with musculoskeletal and cognitive (motor learning) variables. Previous research has shown that water polo and handball athletes with better strength and stability of the shoulder complex, trunk (core) and even lower limbs, have better TP (McCluskey *et al.*, 2010; Ferragut *et al.*, 2011; Platanou and Veramenti, 2011; Ortega-becerra, Pareja-blanco and Jiménez-reyes, 2017; Noronha *et al.*, 2022). Whole muscle groups or regions are frequently assessed, rather than specific muscles and joint ranges which may limit the effectiveness of specific interventions.

Previous findings in overhead sports, baseball in particular, have been presumed to be relevant and applicable to athletes participating in all overhead sports. However, Dutton *et al.*, (2019) demonstrated that cricket players had a unique musculoskeletal profile and that did not reflect the typical throwers shoulder and this highlighted the need for research of this nature to be conducted in specific overhead sports.

Thus, to improve TP in water polo, more detailed data is needed in order to make correlations between specific variables and TP. This study therefore aims to investigate the relationships between musculoskeletal variables and TP in male high school water polo athletes.

3.3 Methods

This study used a cross sectional design to determine whether there were correlations between specific musculoskeletal variables and TP in adolescent male water polo athletes. Participants were tested on a single occasion before the water polo season commenced. Data was collected for each participant. This included demographic information, training history, injury history, position, level of play and a shoulder function score in the form of the KJOC questionnaire (Kerlan-Jobe Orthopaedic Clinic). Fifteen musculoskeletal tests that included strength, flexibility, scapula positioning and shoulder stability were then conducted on each participant. All participants then participated in a TP (speed and accuracy) test.

3.3.1 Subjects

Forty-three adolescent male water polo players (age = 15.5 ± 1 year, height = 178.85 ± 6.89 cm, weight = 74.16 ± 13.07 kg) from high school water polo teams in 2022 (based in the Eastern Cape, South Africa) volunteered to participate in this study. Inclusion criteria were water polo players between 14 and 18 years of age who played for the U16 A or B team or 1st, 2nd or 3rd team in the open category and trained at least twice per week in the pool. Players who had an existing shoulder injury at the time of the pre-season screening were excluded from the study. A shoulder injury was defined as shoulder pain that was severe enough to prevent the athlete from training or playing matches. The study was approved by the Human Research Ethics Committee, University of Cape Town (HREC:543/2021)(Appendix I: Ethical approval for studies in this thesis).

3.3.2 Procedures

3.3.2.1 Anthropometric and participant history:

Height (sitting and standing), weight and age (including date of birth) data was recorded and used to calculate each athletes peak height velocity (PHV) by calculating the athletes maturity offset value. The maturity offset value in turn allows one to predict at which age each individual will reach PHV. PHV is a contributing factor in athletic performance due to the association of increase in physical parameters that may accompany it, such as increase in body size, longer limbs and increased power. The formula used to calculate PHV is: PHV age = (-0.0471 × years from peak height velocity) + (0.9175 × biological age) + 14.317 (Mirwald *et al.*, 2001).

Each participant completed a self-administered demographic questionnaire (Appendix II) containing questions relating to medical, injury and training history and current training load in detail. Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow Score Questionnaire (Appendix II) which measures function and athletic performance in the overhead athlete was administered to each player (Alberta *et al.*, 2010).

3.3.2.2 Musculoskeletal variables

The methodology of the specific musculoskeletal variables is detailed in Table 3-1 below In addition; refer to (Appendix IV: Detailed methodology) for a breakdown and detailed methodology.

Table 3-1 Musculoskeletal variables and testing procedures

Type of measurement	Test performed (intra-rater reliability)	Test description	Protocol Reference	Instrument used (if applicable)
Shoulder function questionnaire	KJOC questionnaire (ICC = 0.88)	Self-administered questionnaire evaluating the shoulder and elbow function for overhead athletes.	Alberta *et al.*, (2010)	Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score
Pain Provocation	Hawkins/Kennedy (ICC = 0.93 - 0.97)	GH joint internal rotation with the shoulder at 90° flexion	Cools et al.(2008)	Yes or no for pain provocation on testing
	Neers	Maximal passive GH joint abduction against a stabilised scapula		
	Jobes	Resisted GH joint elevation with the arms in 90° elevation in the scapula plane and the GH joints internally rotated.		
Scapular Upward Rotation	Measured through range of motion (ICC = 0.89 – 0.96)	The inclinometer is placed at 0°. The resting position of the humerus, relative to the vertical, is recorded. Participant is instructed to lift arm into abduction and stop at 45°, 90° and 135° and end of range. Two repetitions are recorded in each range and the average is calculated and used.	Johnson, McClure, & Karduna, 2001; Watson et al., (2005)	A digital inclinometer (Digi-pas DWL80E, Digipas Technologies, Inc, Dundee, England)
Range of Motion	Glenohumeral internal rotation range (passive) (ICC = 0.89 – 0.99)	Supine with arm to be tested positioned with the shoulder at 90° abduction, 90° elbow flexion and the wrist in neutral. Neutral horizontal positioning is ensured by putting a rolled towel underneath the humerus. The arm is rotated internally. No movement of the scapula is permitted.	Kolber and Hanney (2012)	A digital inclinometer (Digi-pas DWL80E, Digipas Technologies, Inc, Dundee, England)
	Glenohumeral external rotation range (passive)	The start position is the same as for GH IR but the shoulder is rotated externally.		

Strength (Isometric)	Glenohumeral internal rotation (ICC = 0.79 – 0.96)	The arm is in 90° GHJ abduction, 90° GH external rotation and 90° elbow flexion. The HHD is placed 2 cm proximal to the ulnar styloid on the ventral forearm.	Hayes *et al.*, (2002)	Hand-held dynamometer (MicroFET 2 Hoggan Scientific, LCC, Salt Lake, Utah, USA)
	Glenohumeral external rotation (ICC = 0.79 – 0.96)	As IR but the HHD is placed 2 cm proximal to the ulnar styloid on the dorsal forearm.	Hayes *et al.*, (2002)	
	Upper Trapezius (ICC = 0.93 – 0.99)	Sitting with arms securely at the side of the torso. HHD is over the superior aspect of the scapula and downward force is applied in the direction of scapula depression.	Cools *et al*. (2014)	
	Lower Trapezius (ICC = 0.93 – 0.99)	Prone position with shoulder in 145° of abduction and full external rotation. HHD placed at distal ⅓ of the lateral aspect of the radius.	Cools *et al*. (2014)	
	Serratus Anterior (ICC = 0.93 – 0.99)	Supine with the shoulder at 90° forward flexion and elbow in full extension. HHD placed in the palm of the hand.	Cools *et al*. (2014)	
	Functional throwing position	Sitting with shoulder in 135° of GHJ abduction, 90° GH external rotation and 45° elbow flexion. The HHD is placed 2 cm proximal to the ulnar styloid on the ventral forearm.	Novel test position	
Flexibility	Pectoralis Minor Length (ICC = 0.83 – 0.87)	Supine with elbows extended and neutral GH rotation. The distance between coracoid process and 4th rib is taken as the pectoralis minor length.	Borstad *et al*. (2008)	Caliper (Mastercraft Vernier Caliper, Mastercraft Tools, Johannesburg, South Africa)

	Posterior shoulder capsule (ICC = 0.91)	Supine with the arm in 90° forward flexion with 90° elbow flexion. Scapula stabilised by examiner and shoulder passively taken into horizontal adduction.	Myers *et al.*, (2007)	A digital inclinometer (Digi-pas DWL80E, Digipas Technologies, Inc, Dundee, England)
Shoulder and Scapula stability and function	CKCUEST (ICC=0.97)	Participants in the push-up position, with their backs straight and parallel to the floor. Hands are on two markers 91.44cm (36 in) apart. For 15 seconds, the participant lifts one hand and touches the weight bearing hand, alternating hands, as many times as they can. This is followed by a 45 second rest and repeated 3 times. An average score is recorded.	Tucci *et al.*, (2014)	Strapping Tape. Tape measure. Stopwatch
Throwing Speed	Maximum throwing speed	Participants performed 5 throws from the 5 metre mark on the side of the pool. The throw mimicked that of a 5 metre penalty shot in water polo.	Ferragut *et al.* (2011)	Radar gun (Stalker Pro, Applied concepts Inc, Texas, USA). Water polo ball (Regulation size (68-71cm circumference) and weight (400-450g) competition ball.)
Throwing accuracy	Accuracy of throw	The test requires participants to take 12 shots at goal from the 5m mark, 5 seconds apart using a standard size 5 water polo balls. The ball is shot at a target called a sharp shooter. Points are awarded for successful shots on target. See Figure 3-2	Pyne *et al.*, (2006)	Sharp Shooter Target. Water polo balls (Regulation size (68-71cm circumference) and weight (400-450g) competition ball.)

*See Appendix IV: Detailed methodology and Appendix V: Musculoskeletal testing positions for illustration and description each testing position.

3.3.2.3 Throwing performance testing

Throwing speed

TS was measured using a radar gun (Stalker Pro, Applied concepts Inc, Texas, USA) as previously described by Ferragut *et al.* (2011). The radar gun (Figure 3-1) was placed behind the goal post and in a perpendicular direction to the participant. Participants were positioned behind a line 5m from the target area. A regulation size (68-71cm circumference) and weight (400-450g) competition ball was thrown at an open goal. Following a general warm up of 5 minutes of swimming and a shoulder warm up, participants were instructed to spend 5 minutes doing some light to moderate throwing at no particular speed to adequately warm up the shoulder joint and become familiar with the testing environment. Following this, the participant was instructed to "throw as hard as possible towards the goals". The participant performed 3 throws from the 5 metre mark on the side of the pool. The throw mimicked that of a 5 metre penalty shot in water polo. The participants had to pick up the ball off of the water and shoot immediately. The highest speed measured was recorded as the participants' maximum throwing speed (MTS).

Figure 3-1 The Stalker Pro radar gun

Throwing accuracy

TA was measured using a similar method as used to test Australian junior elite male water polo players (Pyne *et al.*, 2006). The test required participants to take 12 shots at goal, 5 seconds apart, with a ball passed to them immediately after each shot. The participant picked up the ball and shot on each blow of the whistle. The face of the goals was covered with a canvass target called a "sharp shooter" (Figure 3-2). The target covered the face of the goals, except for an open gap (30 x 30cm) in each corner that may allow a ball to pass through if shot accurately. Participants were instructed to aim for each cut-out corner of the goals, working in a clockwise direction from top left. A time keeper blew the whistle for each throw to ensure that the 5 second gaps were accurately timed. The participants were scored in a yes/no fashion. Only a full passing of the ball through the correct targeted hole gave them a single point.

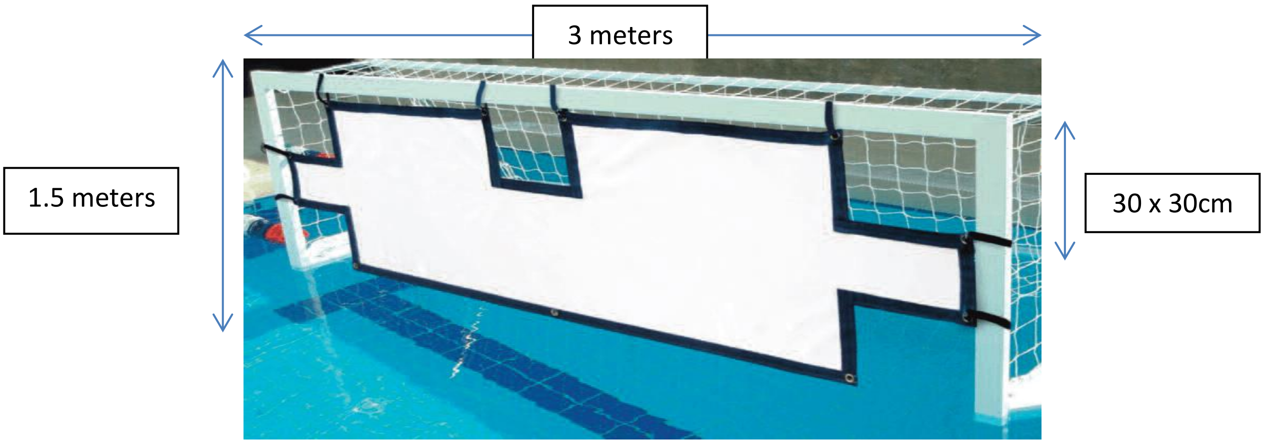

Figure 3-2 Sharp shooter net and scoring allocation

3.3.3 Statistical analysis

Data was analysed using the R studio software (R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/).

Hypothesis testing was conducted for all 31 numerical variables (which included dominant and non-dominant variables). T-tests were used since the data set only contained 2 variables. If the data was not normally distributed an equivalent non-parametric test was used.

The Shapiro-Wilk test was employed to assess the normality of each variable under investigation. If the test indicated that both variables followed a normal distribution, an independent t-test was subsequently performed. If either of the variables were not normally distributed then the Wilcoxon rank sum test was conducted.

Before hypothesis testing was conducted, missing values were replaced. For numerical values, the missing data was substituted with the group mean, for categorical values the missing data was substituted with the group median (Kaiser, 2014). Details of the reason for using a mean value is described in Table 3-2.

Table 3-2 Replaced data

Phase of testing	Data replaced	Reason
Initial testing	SA ND	Shoulder pain on that test
	CKCUEST	Wrist pain
Follow up testing	Throwing performance	Did not attend
	Throwing performance	Thumb injury
	PSC	Data captured incorrectly

*Each line symbolises 1 participant

A linear regression analysis was conducted for TS and a Poisson regression was done for TA for all of the musculoskeletal variables. Eight variables were found to be significant ($p<0.05$) and correlated with TS with only one significant factor ($p<0.05$) correlating with TA.

Independent variables that were significantly ($p< 0.05$) correlated with TS in the bivariate analysis were then added to a multivariable regression. Four variables were found to be significantly correlated with TS after the multivariate regression was completed.

3.4 Results

3.4.1 Participants

The mean and standard deviation of all musculoskeletal and anthropometric variables for the group are given in Table 3-3.

Table 3-3 Musculoskeletal and anthropometric variables (n = 43)

Musculoskeletal variable	**Mean SD**
Anthropometric variables	
PHV	13.86 ± 0.69
Age	15.55 ± 1.00
Mass	74.16 ± 13.07
KJOC	90.30 ± 7.58
Musculoskeletal variables	
PSC	80.42 ± 5.97
USR	-11.24 ± 5.94
USR 45°	-8.90 ± 5.38
USR 90°	-5.36 ± 2.95
USR 135°	14.21 ± 5.88
USR 180°	25.02 ± 5.74
GHIRS at 90°	201.96 ± 51.51
Functional throwing range at 135°	216.06 ± 55.52
GHIRR	52.46 ± 9.58
GHERR	108.19 ± 11.04
Pec Length	14.74 ± 1.44
GHERS	137.98 ± 30.34
SA Strength	508.43 ± 89.31
LT Strength	89.80 ± 19.70
UT Strength	727.77 ± 114.02
CKCUEST	26.21 ± 3.61

PHV: Peak height velocity, KJOC: Kerlan-Jobe Orthopedic Clinic shoulder and elbow, PSC: Posterior shoulder capsule, USR: Upward scapula rotation, GHIRS: Glenohumeral internal rotation strength, GHIRR: Glenohumeral internal rotation range, GHERR: Glenohumeral external rotation range, GHERS: Glenohumeral external rotation strength, SA: Serratus anterior, LT: Lower trapezius, UT: Upper trapezius, CKCUEST: Closed kinetic chain upper extremity stability test.

3.4.2 Throwing performance

Table 3-4 below depicts throwing speed (km/h) and accuracy measures (n = 43).

Table 3-4 Throwing speed (km/h) and accuracy measures (n = 43)

Performance measure	**Mean SD**	**Median IQR**
Throwing Speed (km/h)	58.15 ± 6.17	58.7 ± 8.55
Throwing Accuracy (points/12)	4.04 ± 1.68	4 ± 2

SD: Standard deviation, IQR: Interquartile range

The mean KJOC score was 90.3 ± 7.5. It did not correlate with TS but approached significance (r = -0.01, p = 0.08) for TA. Seventeen of 43 athletes tested positive for at least one of the pain provocation tests, with three of these athletes having positive signs in two or more of the tests. TP was not different for athletes with or without positive pain provocation tests.

Bivariate analysis showed the following variables to be correlated to TS: age (15 – r = 8.83, p = 0.001) (16 – r = 9.36, p = 0.000) (17 – r = 9.95, p = 0.000), CKCUEST (r = 0.71, p = 0.006), dominant arm posterior capsule length (r = 0.45, p =0.003), Pectoralis minor length (r = 2.35, p = 0.00), glenohumeral internal rotation strength at 90° (r = 0.06, p = 0.000), functional throwing position strength at 135° (r = 0.05 , p = 0.002), glenohumeral external rotation strength (r = 0.07 , p = 0.018) and lower trapezius strength (r = 0.10 , p = 0.033). A full table of results for all variables for TS and TA can be viewed in Appendix VI: All musculoskeletal variables and their correlation with speed and accuracy (bivariate analysis).

The multivariance linear regression results (Table 3-5) showed that four variables (age, posterior capsule length, glenohumeral internal rotation strength at 90° and pectoralis minor length) combined accounted for 64% of the variance in the throwing speed test (R^2 = 0.64). The average TS increased with each year of age (14 Average: 50.56km/h, 15 Average: 59.4km/h, 16 Average: 59.9km/h, 17 Average: 60.5km/h). An increase in length of 1 degree (°) of the posterior capsule caused a TS increase of 0.30km/h. For every 1 unit (cm) increase in pectoralis minor length, the TS increased by 1.27km/h, which is a meaningful increase in speed. For every 1 unit (N) increase in strength at 90°, the TS increased by 0.04km/h.

The four variables associated with TS are represented graphically below.

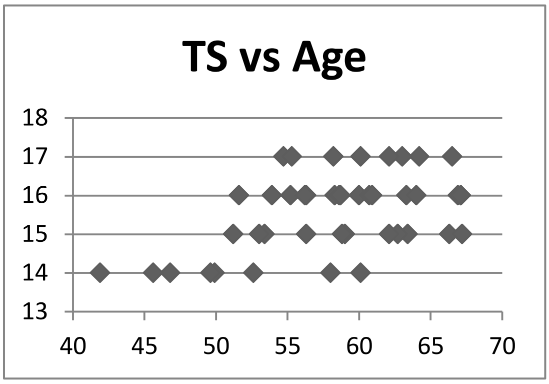

Figure 3-3 Throwing speed and age

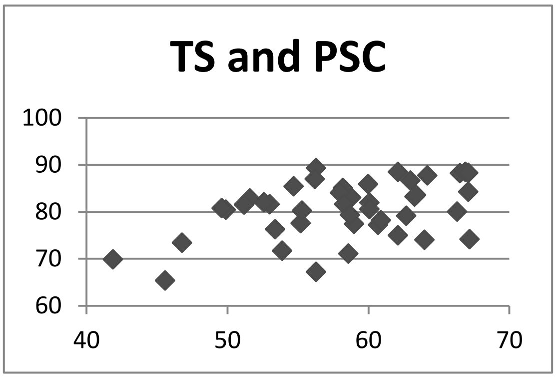

Figure 3-4 Throwing speed and posterior shoulder capsule length

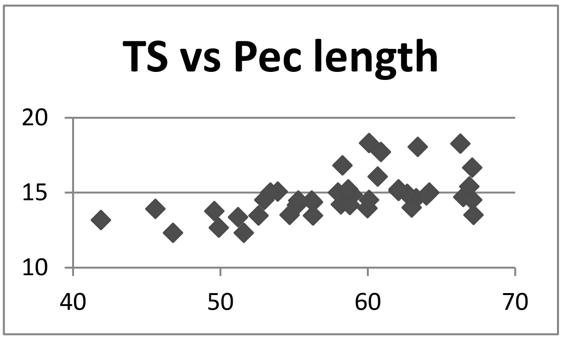

Figure 3-6 Throwing speed and pectoralis minor length

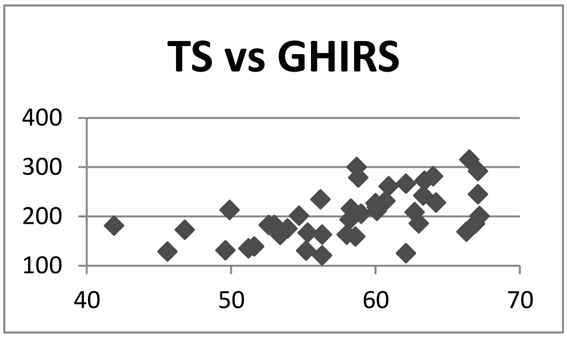

Figure 3-5 Throwing speed and glenohumeral internal rotation strength at 90°

Only the CKCUEST (r = 0.01, p = 0.03) correlated with TA. In this study, every unit increase in stability (CKCUEST total) correlated with TA improvement of 0.01.

The relationship between TA and the CKCUEST is represented graphically below.

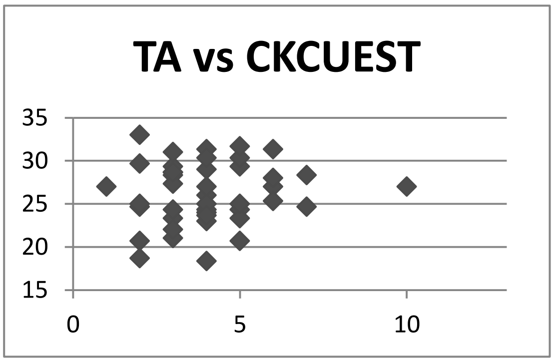

Figure 3-7 Throwing accuracy and the CKCUEST

Table 3-5 Variables significantly correlated with throwing speed and accuracy.

	Variable	Coefficient	95% CI	p Value
Throwing Speed				
	Age 15	6.097	1.813 – 10.381	0.007
	Age 16	5.546	1.318 – 9.774	0.012
	Age 17	4.550	-0.244 – 9.345	0.067
	PSC	0.301	0.061 – 0.540	0.015
	Pectoralis minor length	1.272	0.117 – 2.427	0.032
	LT strength	-0.037	-0.128 – 0.052	0.407
	GHERS	-0.009	-0.070 – 0.030	0.757
	GHIRS 90°	0.046	0.006 – 0.085	0.022
	Functional throwing range at 135°	-0.000	-0.035 – 0.034	0.959
Throwing Accuracy				
	CKCUEST	0.012	-0.003 – 0.002	0.030

PSC: Posterior shoulder capsule, GHIRS: Glenohumeral internal rotation strength, GHERS: Glenohumeral external rotation strength, LT: Lower trapezius, CKCUEST: Closed kinetic chain upper extremity stability test.

3.5 Discussion

This study provides novel evidence for musculoskeletal predictors of TP in adolescent water polo players. This evidence adds to the body of research on musculoskeletal variables contributing to TP in other sports, such as cricket, handball, baseball and other overhead throwing sports (Ahmed, Brown and Gray, 2020; Djanis, 2021; Nuhmani, 2022). The primary outcomes of this study were that age, posterior shoulder capsule flexibility, glenohumeral internal rotation strength at 90° and pectoralis minor length correlated with TS and that the CKCUEST correlated with TA. Studies have shown correlations with anatomic variables and TP in other sports. Dominant pectoralis minor length was correlated with TA in amateur adult cricket players while non-dominant hip abduction strength correlated with TS (Ahmed, Brown and Gray, 2020). One repetition max bench press and dominant sided glenohumeral internal rotation strength correlated with throwing velocity in sub-elite and elite cricket players, while general TP in this study population was correlated with stride length, glenohumeral external rotation range and internal rotation strength (Freeston *et al.*, 2016; Djanis, 2021).

In baseball pitchers it is proposed that adaptive changes to the dominant arm glenohumeral joint (increased external rotation range and posterior capsular stiffness) caused by repetitive throwing, lead to greater TS. This is often accompanied by an increase in injury risk due to a development of GIRD, rotator cuff impingement and Bennett lesions (Pozzi *et al.*, 2019; Zajac and Tokish, 2020; Félix Croteau *et al.*, 2021; Hoppe *et al.*, 2022). With focus on performance, the data has shown that athletes who had better proprioception and core strength, had superior pitching accuracy (Lust *et al.*, 2016).

When combined, specific rotator cuff strength, generalised upper body strength and mobility, core strength and stability and lower body (hip) mobility were all associated with increased pitching velocity (Palmer *et al.*, 2015; Sakata *et al.*, 2019; Oranchuk, Ecsedy and Robinson, 2021), with one study also finding a concomitant significant decrease in injury risk in youth baseball athletes (Sakata *et al.*, 2019).

3.5.1 Predictors of throwing speed:

Age:

Earlier water polo studies have found that older water polo athletes are generally bigger and stronger (body composition and superior anthropometric measurements) and more experienced had greater TS and superior TP (Platanou and Veramenti, 2011; Ramalheira et al., 2022). These findings are comparable to this study, where the average TS increased with each year of age.

Posterior shoulder capsule:

A more flexible posterior capsule was linked to enhance TS in this study. In youth baseball, the addition of posterior shoulder stretching protocols decreased the incidence of shoulder and elbow and demonstrated a concomitant increase in TS (Sakata *et al.*, 2019).

Posterior shoulder stiffness is identified as being one of the most common physiological modifications seen in the dominant shoulder of the overhead throwing athlete (Cools *et al.*, 2015). Both reduced glenohumeral internal rotation range and horizontal adduction are clinical signs of this stiffness. They are attributed to a tight posterior capsule and muscle contracture resulting from micro-trauma caused during the deceleration phase of throwing (Cools *et al.*, 2015; Harput *et al.*, 2016; Bakshi and Freehill, 2018; Kay *et al.*, 2018; Isaac *et al.*, 2022). Posterior inferior tightness may lead to a narrowing of the subacromial space and subacromial impingement (Huffman, Tibone and Mcgarry, 2006; Harput *et al.*, 2016).

Pectoralis minor length:

In this study, a longer pectoralis minor muscle was associated with a greater TS and a shorter pectoralis minor muscle was found to impact TS negatively. Similarly, a cricket study, correlated pectoralis minor length on the non-dominant side and superior TS (Ahmed, Brown and Gray, 2020).

Altered scapula kinematics (decreased scapular posterior tilt and increased scapula internal rotation with arm elevation) were found in water polo players with shortened pectoralis minor and latissimus dorsi muscles and weak serratus anterior and lower and middle trapezius (Tate *et al.*, 2009; Laudner and Williams, 2013; Mukhtyar, Mitra and Kaur, 2014). Scapula muscle imbalance from reduced pectoralis minor length may cause scapula dyskinesis, increasing glenohumeral contact and so, cause rotator cuff impingement (Escamilla *et al.*, 2009; Borstad and Ludewig, 2013). This supports stretching the pectorals and balancing strong internal rotators with strong external rotators as suggested by previous publications (Ahmed, Brown and Gray, 2020).

Glenohumeral internal rotation strength at 90°:

TS increased as the strength of the internal rotators increased at 90° shoulder abduction. Our findings, with regards to the relationship between internal rotation strength and TS are supported by the findings of other studies investigating elite female (Platanou and Veramenti, 2011) and youth (Ramalheira *et al.*, 2022) water polo players, and elite male cricket players (Djanis, 2021). This was however not supported in amateur cricketers where hip abduction and non-dominant pectoralis minor length were correlated with TS (Ahmed, Brown and Gray, 2020). Therefore, caution must be taken if extrapolating the findings of research across sports, ages and even of competition. These results therefore support the need to strengthen shoulder internal rotation at 90° abduction.

3.5.2 Predictors of throwing accuracy

The CKCUEST (Closed Kinetic Chain Upper Extremity Stability Test) is conducted to evaluate shoulder stability around the scapula muscles and the rotator cuff. Proprioception plays a crucial role in both the CKCUEST and throwing sports, as it is vital for maintaining joint stability, controlling muscle activation, and coordinating upper extremity movements. Athletes heavily rely on accurate proprioceptive feedback to perceive joint angles, limb position, and force production necessary for executing precise and controlled throwing motions (Mota and Ribeiro, 2012). Impairments in proprioception can negatively impact joint stability, muscle control, and coordination, thereby potentially impairing performance and increasing the risk of injury (Mendez-rebolledo *et al.*, 2022). Consequently, it is crucial to assess and address proprioceptive function within the context of the CKCUEST to identify deficiencies, develop targeted interventions, and enhance proprioceptive abilities in throwing sports, ultimately leading to improved performance and reduced injury risks (Mendez-rebolledo *et al.*, 2022).

A better CKCUEST score and functional throwing performance index (FTPI), gave a good indication of shoulder stability and scapular control and correlated to TA in university baseball pitchers (Lust *et al.*, 2016). The results of this study suggest that better glenohumeral and scapular control lead to better control and placement of the ball during shooting in water polo. In this study, stability (CKCUEST total) was correlated with a small increase of TA but caution should be taken when interpreting this result as we are unsure whether this holds practical significance in this context.

There were a number of variables that were correlated with TS prior to inclusion in the multivariate analysis. While a larger sample size is required to assess their potential in predicting speed the following variables may be of future interest in TP in water polo.

CKCUEST:

This study found that better stability scores were associated with higher TS. For every one unit increase in stability scores, the TS increased by 0.71km/h. This was supported by (Palmer *et al.*, 2015) who found similar results in collegiate throwing (softball and baseball) athletes. Hams *et al.*, (2019) also found that better in-water proprioception in water polo athletes, correlated with better throwing mechanics and TS. This indicates the importance of a multimodal approach to the shoulder joint. Good proprioception serves as the foundation for stability, control and strength of the shoulder joint and scapula and in turn improves the overall joint function and performance.

The functional throwing strength testing position at 135° abduction:

The functional throwing strength testing position at 135° abduction is a position that involves recruitment of additional muscles to the traditional internal rotation at 90°. TS increased as the strength measurement in this functional shooting position increased. Most strength testing in the literature has been done at 90° but this study included strength testing at 135° of shoulder abduction as it is more comparable to the position of throwing and shooting in water polo. There was some variability in the relationship between strength at 135° degrees and TS and the functional throwing position may be more of a range than a set angle of abduction with some players using a greater angle than others. This could relate to position, experience, age or even individual musculoskeletal variables. However, this does highlight a need to include strengthening above 90° of abduction. In this study, for every 1N increase in strength at 135°, the TS increased by 0.06km/h.

Glenohumeral external rotation strength:
There was a correlation between glenohumeral external rotation strength and TS. For every 1N increase in strength, the TS increased by 0.07km/h. Other studies have shown similar findings. Stronger glenohumeral external rotators, were found to be correlated with increased serve velocity in youth female volleyball players (Turgut *et al.*, 2019).

The balance of external rotation to internal rotation (ER:IR) strength may also be important. Bloomfield *et al.* (1990) and Olivier and Daussin (2018) found water polo players had a muscle imbalance with a greater glenohumeral internal rotation strength relative to external rotation strength. Eccentric strength of the external rotators was reduced, which would decrease the ability of the arm to decelerate and balance the shoulder in the follow through of the throw and potentially increasing the risk of injury. The ER:IR strength ratio in this study population was 1.4:2 (68%). In baseball pitchers, the "acceptable imbalance" was between 66% and 75% (Hurd *et al.*, 2011). Water polo studies using high school and another with sub-elite athletes, showed no correlation between ER:IR strength and injury risk, but did find that weaker internal and external rotation was a significant indicator of future injury (Hams, Evans, Waddington, *et al.*, 2019; Croteau, 2021).

Lower trapezius strength:
Good scapula stability is required to support the glenohumeral joint and in turn provide general stability to the whole shoulder complex. In addition to a positive CKCUEST test, correlation between lower trapezius strength and TS further supports the need for good scapula stability. For every 1 unit increase in strength, the TS increased by 0.1km/h. No studies have looked at the role of lower trapezius strength in throwing velocity as a stand-alone muscle, but due to its role in shoulder and scapular stability, this is likely to tie in with the stability and proprioception tests and CKCUEST.

KJOC
This is a standardised performance test based on upper extremity function for overhead athletes (Kraeutler *et al.*, 2013). The group mean in this study was 90, which is comparable with what has been identified in professional baseball pitchers (Kraeutler *et al.*, 2013). Elite cricket players were found to have lower KJOC scores, where scores below 90 may indicate that an athlete is playing with pain or injury which may compromise performance. A lower preseason KJOC score was associated with higher future injury risk (Dutton, Tam and Gray, 2019).

3.6 Limitations

Due to the high number of variables (n = 8) that were correlated with speed in this group (after the linear regression analysis) and the population size (n = 43), caution should be exercised when interpreting the result of the multivariate analysis for TS. These results should be seen as preliminary and future research should be done using a larger sample size to avoid generalisability and to improve validity and reliability and therefore enable more robust inferences and a deeper understanding of the relationship between the variables and TS. Additionally, only with a more robust data set can we accurately assess the meaningfulness and real-world implications of the association between stability and TA.

3.7 Conclusion

This study builds on limited evidence relating to musculoskeletal factors and TP in adolescent male high school water polo players. Only 5 of the 15 tests correlated with TP after the multivariate analysis. The primary outcomes of this study were posterior capsule length, glenohumeral internal rotation strength at 90°, age and pectoralis minor length having been correlated with TS when all variables were considered concomitantly. The CKCUEST correlated with TA. This highlights the importance of having a well-balanced program that covers strength of the rotator cuff, scapula and rotator cuff stability and flexibility in this water polo population.

Chapter 4

Can a four week in-season conditioning program influence musculoskeletal risk factors, reduce injury risk and change throwing performance in adolescent male water polo players?

4.1 Abstract

Objectives: This study aims to investigate the effectiveness of a conditioning programme on musculoskeletal parameters associated with injury risk and throwing performance in adolescent water polo players.

Design: This was a cluster randomised control trial with an in season conditioning intervention program.

Methods: Forty-three adolescent male high school water polo athletes were tested twice, four weeks apart, using a battery of 15 upper limb musculoskeletal tests (strength, range of motion, scapula stability, and pain). Throwing performance (TP) was evaluated in the pool by testing throwing speed (TS) and throwing accuracy (TA). The experimental group participated in a specific conditioning program two days a week, for a four week period, between the two testing occasions. The control group participated in their regular water polo training.

Results: There were no significant differences between the two groups ($p < 0.01$) for any of the musculoskeletal variables or throwing performance variables following the four week exercise intervention period.

Conclusion: A four week in season conditioning program did not alter the musculoskeletal profile, influence injury or throwing performance of male adolescent water polo players.

Keywords: Throwing performance, water polo, musculoskeletal, throwing speed, throwing accuracy, adolescent, intervention, conditioning.

4.2 Introduction

Water polo in recent years, has gained momentum in popularity and participation, both in South Africa and internationally. The prevalence of musculoskeletal injury has also increased significantly with the growing number of participants (Ellapen *et al.*, 2013).

Adolescent male water polo players report a 51% prevalence of musculoskeletal shoulder pain over a 12 month period (Ellapen *et al.*, 2013). These numbers correspond with other international injury surveys of adult populations, where water polo shoulder injury was reported as 38-80% (Webster, Morris and Galna, 2009). The incidence of shoulder injuries in water polo is comparable to other sporting codes such as swimming, tennis, baseball and handball (Cools *et al.*, 2010, 2015; Andersson *et al.*, 2017; Tate *et al.*, 2017; Keller *et al.*, 2018) but is greater than volleyball and cricket (Giles and Musa, 2008; Reeser *et al.*, 2010; Dutton, 2012). The existing body of literature available for the identification of risk factors for shoulder injuries in overhead athletes is limited (Cools *et al.*, 2015).

Water polo players had a muscle imbalance with a greater internal rotation strength relative to external rotation (Bloomfield *et al.*, 1990; Olivier and Daussin, 2018). Eccentric strength of the external rotators was reduced, which would decrease the ability of the arm to decelerate and balance the shoulder in the follow through of the throw and potentially increasing the risk of injury (Bloomfield *et al.*, 1990; Olivier and Daussin, 2018).

Altered scapula kinematics (decreased scapular posterior tilt and increased scapula internal rotation with arm elevation) were found in water polo players with shortened pectoralis minor and latissimus Dorsi, weak serratus anterior and lower and middle trapezius (Tate *et al.*, 2009; Laudner and Williams, 2013; Mukhtyar, Mitra and Kaur, 2014). Scapula muscle imbalance from reduced pectoralis minor length may cause scapula dyskinesis, increasing glenohumeral contact and so, cause rotator cuff impingement (Escamilla *et al.*, 2009; Borstad and Ludewig, 2013). In players with shoulder pain, scapula upward rotation was shown to decrease after an intense practice, and so potentially increase rotator cuff impingement (Mukhtyar, Mitra and Kaur, 2014).

Glenohumeral internal rotation deficit or GIRD has been defined as a loss (20° or greater) of internal rotation range of motion in the dominant versus non-dominant arm (Keller *et al.*, 2018). In a meta-analysis and systematic review, Keller *et al*. (2018) determined that there was no correlation between GIRD and shoulder injury in overhead throwing athletes. However, in overhead athletes with GIRD and an external rotation gain, injury was more likely (Keller *et al.*, 2018). GIRD has been attributed to humeral retroversion and posterior capsular stiffness (posterior capsular thickening and muscular adaptations) (Zajac and Tokish, 2020). While it's possible to modify certain aspects of GIRD, it's important to note that a portion of it is inherently non-modifiable due to its association with humeral retroversion.

Shoulder injury in water polo has been attributed mainly to “overuse” from the accumulative demands of swimming, throwing and defending (Hams, Evans, Adams, *et al.*, 2019a) and this was supported by the results from a systematic review by Webster, Morris and Galna (2009). The physical demand on the upper limbs is greater in water polo due to a lack of a stable base, which may increase the risk of musculoskeletal injury (Webster, Morris and Galna, 2009). Although several of the risk factors that have been identified are intrinsic risk factors, the results of a study by Lebedew *et al.* (2012) on female national level water polo players, showed that shoulder soreness increased with an increase in the number of overhead shots taken at goal during training, and was aggravated with shorter rest periods between shots, highlighting the importance of the extrinsic risk factor of training.

Due to various differences in definition, lack of clarity on exercises used or poor quality research, there is no gold standard exercise protocol yet for overhead athletes (Wright *et al.*, 2017). Further, there is limited evidence for water polo injury risk and intervention protocols (Webster, Morris and Galna, 2009) and even less evidence for the adolescent age group (Ellapen *et al.*, 2013; Worsley *et al.*, 2013; Gradidge *et al.*, 2014; J. Zaremski, Zeppieri and Tripp, 2019).

Exercise interventions for injury prevention and/or performance in overhead sports ranged in duration from 4 weeks to 12 months, with an average time of 6-8 weeks. Strength and stretching protocols also varied and the length of time of the intervention didn't appear to correlate to efficacy of the intervention although the minimum time for a program to show efficacy was 4 weeks. The protocols encompassed a variety of exercise modalities, such as targeted shoulder exercises, plyometric routines, stretches for the shoulder and elbow, exercises promoting core and trunk stability, and comprehensive whole-body (including legs) strength exercises. These exercises utilized a range of equipment, including bands, dumbbells, barbells, medicine balls, cable weight stations, and weighted balls (baseballs) (Bloomfield *et al.*, 1990; Fernandez-fernandez *et al.*, 2013; Palmer *et al.*, 2015; Raeder, Fernandez-Fernandez and Ferrauti, 2015; Lust *et al.*, 2016; Reinold *et al.*, 2018; Sakata *et al.*, 2019; Turgut *et al.*, 2019; Oranchuk, Ecsedy and Robinson, 2021; Jha *et al.*, 2022). Refer to Table 2-1 Intervention programs in overhead sports.

Therefore, this study aims to investigate the effectiveness of a conditioning programme on musculoskeletal parameters associated with injury risk and TP in adolescent water polo players.

4.3 Methods

This study was a cluster randomised control trial with an in season conditioning, intervention program. Participants were tested on two occasions; once before the water polo season commenced and once after the four week intervention, where identical musculoskeletal and TP tests were repeated. At the initial testing session, data was collected for each participant. This included demographic information, training history, injury history, position, level of play and a shoulder function/KJOC questionnaire (Kerlan-Jobe Orthopaedic Clinic). 15 musculoskeletal variables that included strength, flexibility, scapula positioning and shoulder stability were then conducted on each participant. Throwing performance (speed and accuracy) test was evaluated for each participant.

Participants were split into two randomised groups; an intervention group and a control group. Each age group was split into two equal groups (control group and intervention group) by simple randomisation. During the 4 week period, a conditioning program was completed twice a week for 10 minutes, by the intervention group. This intervention program is unique and designed by the author using identified performance variables, as well as factors identified in the literature that may influence injury risk in water polo and other overhead sports. The control group participated in their normal water polo training which consisted of a basic swimming "warm up" set and pool based water polo specific training. Athletes completed a weekly logbook (Appendix VII: Injury and load monitoring questionnaire/logbook) on training load and pain. This data was collected via a google document with short drop down answers or text which was sent to their phone on a weekly basis.

4.3.1 Subjects

Forty-three adolescent male water polo players (age = 15.5 ± 1 year, height = 178.85 ± 6.89 cm, weight = 74.16 ± 13.07 kg) from high school water polo teams in 2022 (based in the Eastern Cape, South Africa) volunteered to participate in this study. Participants between 14 and 18 years of age were included if they played for the U16 A or B team or 1st, 2nd or 3rd team in the open category and trained at least twice a week in the pool. Players who had an existing shoulder injury at the time of the pre-season screening were excluded from the study. A shoulder injury was defined as a limitation to participate in training or matches due to shoulder symptoms. The study was approved by the Human Research Ethics Committee, University of Cape Town (HREC:543/2021) (Appendix I: Ethical approval for studies in this thesis).

4.3.2 Procedures

Detailed anthropometric and participant history, musculoskeletal variables and TP testing are outlined in section 3.3.2 Procedures.

Table 4-1 below shows a basic outline of testing that was done:

Table 4-1 Musculoskeletal and performance testing

Variable	Test
Overhead function and athletic performance of the shoulder	Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow Score
Impingement	Hawkins-Kennedy Neer's Jobe's
Range of motion	Upward scapula rotation GHJ internal and external rotation (GIRD)
Strength	GHJ internal and external rotators Scapula stabilisers (Serratus Anterior, Lower Trapezius and Upper Trapezius)
Length	Pectoralis Minor GHJ posterior capsule
Shoulder stability	Closed kinetic chain Upper extremity stability
Throwing performance	Speed and accuracy

GHJ: Glenohumeral joint

4.3.2.1 Intervention Exercises

The exercise protocol was devised by a Physiotherapist who works with adolescent water polo players. The intervention was based on a combination of previous interventions from studies that were effective at reducing shoulder injury risk and or improving TP in other overhead sports (Cools *et al.*, 2007; Niederbracht *et al.*, 2008; Andersson *et al.*, 2017; Kang *et al.*, 2019; J. Zaremski, Zeppieri and Tripp, 2019; Fredriksen *et al.*, 2020) and the findings of the initial testing session. The bi-weekly intervention sessions (Table 4-2) were between 10-15 minutes and were performed before practice at the pool. The exercises were done in partners where possible to encourage participation and compliance (Holt *et al.*, 2020). The strength exercises were set up with repetitions and sets based on guidelines from a meta-analysis that assessed youth resistance training. The guidelines describe a resistance program that is set up with 2-3 sets of 8-15 repetitions with loads between 60% to 80% of the 1 RM, in a youth population (Faigenbaum *et al.*, 2015). Stretches were done for 60 seconds for 2 sets using previously described stretching positions (McClure *et al.*, 2007). Appendix VIII: Exercises and explanations provides a comprehensive breakdown of each exercise, along with a rationale for their inclusion.

Table 4-2 Exercises

Target muscles/structures	**PHASE 1: (Week 1)**	**PHASE 2: (Week 2-3)**	**PHASE 3: (Week 4)**
Serratus Anterior (Decker *et al.*, 1999)	Knee push up plus	Standard Push up Plus	Banded push up plus
Trapezius –Upper (Escamilla et al, 2009)	Standing scaption 80° - 120°	Standing scaption 80° - 120° (Banded)	Standing scaption 80° - 120° (Banded – increase in resistance if appropriate)
Trapezius – Middle and Lower (Escamilla *et al.*, 2009)	Prone Isometric horizontal abduction Y	Theraband horizontal abduction Y	Theraband horizontal abduction Y (Increased resistance)
Teres Minor & Infraspinatus (Escamilla *et al.*, 2009)	Standing external rotation (with Theraband)	Standing (90° abduction) Theraband ER	Standing (90° abduction) Theraband ER (One foot)
Latissimus Dorsi, Rhomboids, Trapezius and Posterior Deltoid.	Mid rows (45° Abduction) with Theraband)	Low, mid and high rows (Increase resistance)	Low, mid and high rows (Increase resistance & done on one leg)
Infraspinatus, Teres Minor, Subscapularis & Pectoralis Major (McCluskey *et al.*, 2010; Fernandez-fernandez *et al.*, 2013; Raeder, Fernandez-Fernandez and Ferrauti, 2015; Kevin E. Wilk *et al.*, 2016)	Squat + Slam ball throw	Squat + Slam ball throw	Squat + Slam ball throw
Core (Özekli Mısırlıoğlu, 2018)	Bird - Dog (basic)	Bird - Dog (Touching opposite knee to opposite elbow)	Bird - Dog (High plank position)
Posterior shoulder capsule (McClure *et al.*, 2007)	Sleeper stretch*	Sleeper stretch*	Sleeper stretch*

*Stretches were only performed if the participant was found to have a GIRD deficit

4.3.2.2 Weekly logbook

Workload and non-specific shoulder pain and/or injury data was monitored with a weekly Google forms document (Appendix VII: Injury and load monitoring questionnaire/logbook). This weekly questionnaire aimed to monitor each participants shoulder function during the 4 week conditioning period. For the purpose of this study, shoulder pain was defined as a physical complaint or presentation of pain sustained during a match or training, where there was a loss of playing time (training or match) or a modification of activity because of pain. Participants were asked whether they had missed a practice and/or match due to shoulder pain. Pain was measured in a visual analogue scale (VAS) and simply rated from 0 (minimum) to 10 (maximum).

Medical management was recorded if participants had sought medical attention. Shoulder strength was described as the perceived ability to perform an activity.

4.3.3 Statistical analysis

Data was analysed using the R studio software (R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/).

Hypothesis testing was conducted for all 31 numerical variables (which included dominant and non-dominant variables) to determine whether at baseline there was a difference between the two groups and to test whether the intervention had an effect over time on musculoskeletal and performance variables of participants.

T-tests were used since the data set only contained 2 groups. Shapiro-Wilks test was used for normality testing each variable. If the variables in both groups were both normally distributed then an independent t-test was conducted. If either of variables were not normally distributed then the Wilcoxon rank sum test was conducted.

Before hypothesis testing was conducted, missing values were replaced. For numerical values, the missing data was substituted with the group mean, for categorical values the missing data was substituted with the group median as described by (Kaiser, 2014). Details of replaced data are shown in Table 4-3.

Table 4-3 Replaced data

Phase of testing	Data replaced	Reason
Initial testing	SA ND	Shoulder pain on that test
	CKCUEST	Wrist pain
Follow up testing	Throwing performance	Did not attend
	Throwing performance	Thumb injury
	PSC	Data captured incorrectly

*Each line symbolises 1 participant. SA ND: Serratus anterior non-dominant, CKCUEST: Closed kinetic chain upper extremity stability test, PSC: Posterior shoulder capsule.

The p-value was set to 0.01 for all tests, as multiple tests (31 variables) were conducted. Using a small value of alpha reduces the chances of a type one error (false positive). Researchers often use a significance level of 0.05 rather than 0.01 due to a balance between controlling type one and type two (false negative) errors and the convention of historical usage, which facilitates comparability across studies and allows for more flexibility in exploratory research.

A two sample Z-test for proportions was conducted to determine if the prevalence of pain was different between the groups. The p-value was 0.469 and the confidence interval was -1, 0.129.

4.4 Results

4.4.1 Participants

Both the control and intervention groups were matched in age and shoulder function (KJOC scores) (Table 4-4). The control group was slightly heavier on average and the experimental group was slightly taller but this was not found to be a meaningful difference.

Table 4-4 Participant demographics – Experimental vs control group (n = 43)

Variable	Experimental (E)	Control (C)
Age (years)	15.5 ± 1.0	15.6 ± 1.0
Weight (kgs)	73.65 ± 8.3	74.69 ± 16.8
Height (cm)	180.92 ± 5.7	176.68 ± 7.4
KJOC (score/100)	90.0 ± 8.1	90.5 ± 7.2

Kgs: kilograms, cm: centimetre

Performance comparisons between groups:

There was no meaningful difference in TS before and after the intervention between the two groups. While TA improved in both the control and intervention groups following the intervention period, these improvements were not meaningful (Table 4-5).

Table 4-5 Throwing performance between groups

Variable	Experimental (E)		Control (C)	
	Initial testing	Follow up testing	Initial testing	Follow up testing
Throwing speed (km/h)	59.9 ± 4.8	59.9 ± 4.9 =	56.3 ± 6.9	55.3 ± 6.8 ˅
Throwing accuracy (score/12)	4.2 ± 1.4	5.8 ± 1.8 ^	3.8 ± 1.9	4.7 ± 2.0 ^

^ : Increase in variable value, ˅ : Decrease in variable value, = No change in variable value

Musculoskeletal variables comparisons between groups after the intervention period:

The results of the intervention demonstrated differences in musculoskeletal variables between the two groups that were tested after the completion of the 4 week intervention period (Table 4-6). However, the results were not statistically meaningful for any of the thirty-one variables.

Table 4-6 Musculoskeletal variables comparison between groups

Variable	Side	Experimental - Pre (E)	Experimental - Post (E)	Control - pre (C)	Control - post (C)
GH internal rotation range (°)	D	54.0 ± 7.8		50.8 ± 11.0	
	NonD	67.2 ± 11.5		61.8 ± 13.6	
GH external rotation range(°)	D	109.5 ± 9.5	100.0 ±11.2 V	106.7 ± 12.4	99.4± 11.6 V
	NonD	92.4 ± 12.3	89.1 ±12.7 V	94.4 ± 12.2	93.0 ±12.7 V
Pectoralis minor length (cm)	D	14.9 ± 3.4		14.5 ± 1.5	
	NonD	15.0 ± 1.1		14.6 ± 1.3	
Posterior shoulder capsule (°)	D	80.8 ± 4.6	82.9± 4.8 ^	80.0 ± 7.2	80.6± 5.3 ^
	NonD	84.1 ± 6.4	81.6 ±7.5 V	84.4 ± 3.9	83.1± 5.4 V
Upward scapula rotation at 0° (°)	D	-9.0 ± 5.1	-8.4 ± 3.4 ^	-13.5 ± 5.9	-9.4 ±4.1 ^
	NonD	-6.91 ± 3.1	-5.2 ± 2.1 ^	-9.1 ± 6.2	-5.3 ±3.1 ^
Upward scapula rotation at 45° (°)	D	-6.8 ± 4.9	-6.0 ± 3.8 ^	-11.0 ± 5.0	-8.4 ±3.7 ^
	NonD	-4.2 ± 2.8	-2.3 ±1.3 ^	-5.5 ± 4.2	-3.4 ±1.8 ^
Upward scapula rotation at 90° (°)	D	-5.1 ± 2.6	-4.8 ± 3.7 ^	-5.5 ± 3.3	-4.6 ±2.6 ^
	NonD	-6.8 ± 4.3	-6.6 ± 4.6 ^	-4.7 ± 3.3	-6.0± 5.2 V
Upward scapula rotation at 135° (°)	D	15.4 ± 2.6	15.4± 7.6 =	12.9 ± 5.7	15.2± 7.5 ^
	NonD	17.9 ± 5.9	18.3 ±5.5 ^	15.3 ± 5.5	19.2± 5.8 ^
Upward scapula rotation at 180° (°)	D	25.8 ± 5.8	25.7 ± 8.9 =	24.1 ± 5.5	26.7 ± 9.1 ^
	NonD	25.9 ± 5.0	26.9 ± 6.9 ^	26.1 ± 8.1	28.7 ± 7.9 ^
GH internal rotation strength (N)	D	212.6 ± 54.7	224.7 ± 57.5 ^	190.7 ± 46.6	196.9 ± 52.3 ^
	NonD	202.1 ± 58.9	224.1 ± 59.0 ^	172.2 ± 55.7	189.4 ± 54.7 ^
GH external rotation strength (N)	D	138.3 ± 35.1	165.6 ± 34.3 ^	137.6 ± 25.22	158.4 ± 32.6 ^
	NonD	130.2 ± 49.5	160.1 ± 46.8 ^	126.3 ± 32.1	148.2 ± 36.3 ^

Serratus anterior strength (N)	D	498.3 ± 90.8	370.8 ± 121.0 ˅	518.9 ± 88.6	357.8 ± 111.2 ˅
	NonD	489.5 ± 96.4	393.0 ± 127.4 ˅	500.7 ± 92.1	328.1 ± 119.3 ˅
Lower trapezius strength (N)	D	92.4 ± 19.0	88.9 ± 19.6 ˅	87.0 ± 20.4	87.6 ± 25.5 ^
	NonD	96.5 ± 36.8	81.8 ± 15.5 ˅	89.0 ± 20.9	85.2 ± 22.7 ˅
Upper trapezius strength (N)	D	710.9 ± 114.9	566.6 ± 103.3 ˅	745.3 ± 113.0	539.9 ± 123.8 ˅
	NonD	661.6 ± 88.7	569.9 ± 96.2 ˅	676.1 ± 119.1	525.5 ± 139.0 ˅
GH internal rotation strength at 135° (N)	D	214.5 ± 56.12	220 ± 53.7 ˅	213.6 ± 57.9	200 ± 43.4 ˅
	NonD	222.3 ± 39.5	213 ± 47.2 ˅	198.9 ± 46.2	188 ± 55.7 ˅
CKCUEST (taps)	N/A	26.7 ± 3.4	30.5 ± 4.4 ^	25.6 ± 3.83	29.1 ± 4.5 ^

^ : Increase in variable value, ˅ : Decrease in variable value, = No change in variable value. GH internal rotation range and Pectoralis minor length values have been excluded from analysis due to follow up testing error.

Pain and injury monitoring

The self-reported pain and load logbook was analysed and there was no meaningful difference in reported shoulder pain observed between the groups over the four weeks (Figure 4-1). Water polo specific training load (hours) decreased over the four weeks as the season came to an end in week four. The training load for week one was nine hours, for week two it was seven and a half hours, for week three it was seven hours, and for week four it was six hours. Training loads were matched between the groups over the weeks. Pain prevalence was highest in week one (67%) and decreased over the four weeks in both groups as seen in Figure 4-2 below.

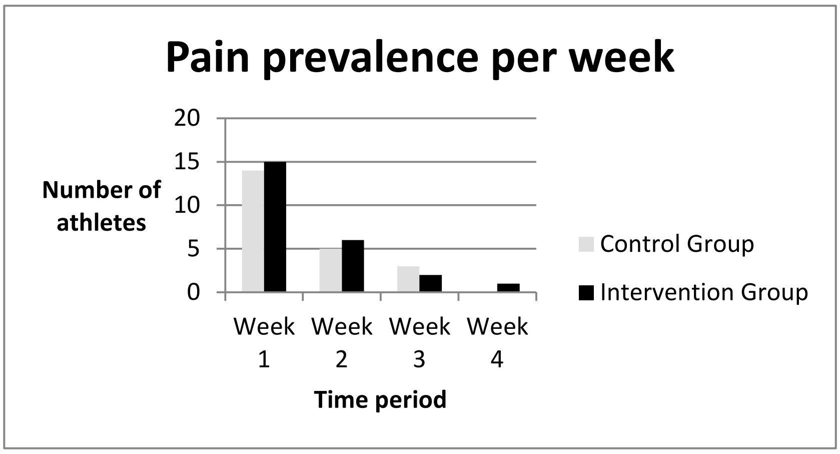

Figure 4-1 Pain prevalence per week

Participants, who reported pain over the weeks of the study, reported that the majority of their pain was attributed to throwing. Some reported pain whist swimming and upper body gym, but this was marginal by comparison (Figure 4-2). No participants had pain that removed them from training or competition and only one participant had two physiotherapy treatment sessions for a minor biceps tendon inflammation that appeared to be linked to a practice where repetitive shooting at goal was done in the first week of the season.

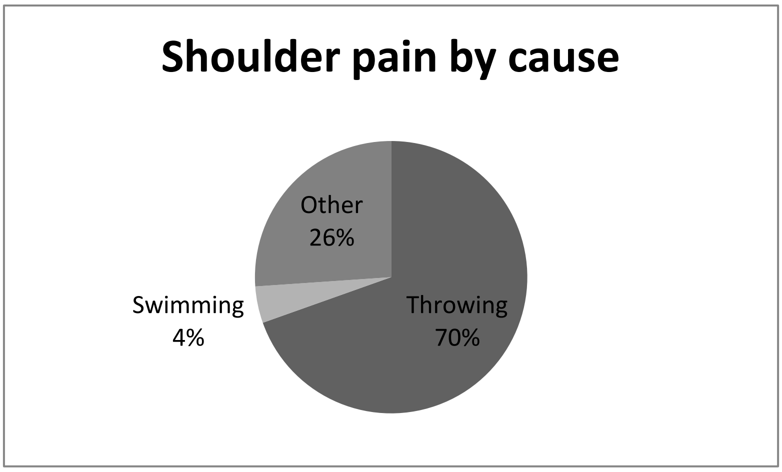

Figure 4-2 Activity associated with shoulder pain

The adherence to the weekly sessions was excellent, as none of the participants were excluded from the study due to consecutive absences. Any missed sessions were rescheduled within the same week which resulted in 100% attendance. The compliance with the log book was excellent for a study of this nature, albeit with a decline over the course of the four week period, as evidenced by a reduction from 100% in the first week, to 81% in the second week, 70% in the third week, and 63% in the fourth week.

4.5 Discussion

The outcomes of this study suggest that the intervention program did not positively influence TP (speed or accuracy), musculoskeletal variables (risk factors), or the prevalence of shoulder pain after the four week intervention.

Throwing performance and musculoskeletal variables

There was no significant change in the in TS or TA for either group after the 4 week intervention period but potential causes for deviations in variables will be explored and discussed.

Shoulder function (KJOC scores) were high (mean of 90) indicating a high functional ability for this group as a whole and is therefore comparable with what has been identified in professional baseball pitchers (Kraeutler *et al.*, 2013). Elite cricket players were found to have lower KJOC scores, where scores below 90 may indicate that an athlete is playing with pain or injury which may compromise performance. A lower preseason KJOC score was associated with higher future injury risk (Dutton, Tam and Gray, 2019). This suggests that the scope for improvement in this group was lower and thus may have reduced the opportunity for demonstrating improvement.

The strength values for serratus anterior and upper and lower trapezius appear to have decreased in the measured parameters for both groups but not significantly so. This could be due to various factors such as fatigue both acute and chronic. Notably, some of the senior athletes had had a water polo tournament that finished four days prior to the follow up testing. It has been shown in previous studies that the serratus anterior specifically, fatigued rapidly in swimmers due to the muscle firing at 20% of its maximum for long periods of time (Pink *et al.*, 1996).

The observed change in improved upward scapula rotation was noted in both groups. Improved scapula position could be attributed to improved elevation, performed by the levator scapula muscles or the contribution of improved scapula stability identified on the CKCUEST for both groups.

External rotation strength improved at follow up testing in both groups, but there were no changes in TP. This strength improvement could be due to a general training effect associated with the four week water polo training. It may also be explained in part by a familiarity with the testing technique. Banded exercises have previously been used to improve ER strength in tennis players and swimmers and showed meaningful improvement (2.6%) in TS in a softball population (Niederbracht *et al.*, 2008; Batalha *et al.*, 2014; Oranchuk, Ecsedy and Robinson, 2021). These programs however had a longer duration (5-16 weeks) and higher frequency (3-4 times per week) than this study.

Both groups demonstrated an improvement in shoulder stability, measured by the CKCUEST at follow up testing. These results did not reach statistical significance and were not significantly different between groups. Open and closed chain exercises are effective in improving proprioception and joint reposition sense and in a baseball study, were found to correlate with TA (Rogol, Ernst and Perrin, 1998; Lust *et al.*, 2016). These above mentioned studies were both conducted three times a week for six weeks which is longer in duration and more frequent than this study. The current study included exercises in both open and closed chain positions which may have contributed to the improvements in stability, albeit not significant for changes in strength or TA. However, it is more likely that the changes could be attributed to participants being generally better conditioned at the end of the season and also more familiar with the technique or task at the follow up testing due to the improvements in both groups.

Posterior capsule stretching was found to be effective over four weeks in patients with decreased internal rotation. This study included two sets of 60 seconds, twice a week, whereas McClure *et al.*, (2007) did this daily and did five repetitions of 30 seconds which was much higher than our dosage. The current study only included posterior capsule stretching for the individuals that required it within the exercise group making it difficult to investigate the effectiveness of this component of the exercise programme. Stretching for the posterior capsule has proved successful in maintaining or restoring scapular kinematics and reducing pain or injury risk and therefore is a worthwhile addition to an exercise protocol when deemed necessary (McClure *et al.*, 2007; Maenhout *et al.*, 2012; Pellegrini *et al.*, 2016; Shitara *et al.*, 2017; Turgut *et al.*, 2017; Chepeha *et al.*, 2018; Sakata *et al.*, 2019).

Programs that included a combination of both core, scapula stability and specific rotator cuff exercises were also found to show improvements in TS and one program in university baseball players showed improvements in accuracy as well (Lust *et al.*, 2016). The exercises used in the current study were very similar; however the duration of each session (30-45 minutes), the weekly frequency (three times per week) and the overall duration (six weeks) were different in the other studies. Comparison between intervention programmes in the literature is very difficult for this reason.

Lower body strength and power in both female and youth water polo athletes has also been attributed to superior in water jump height, throwing and swimming performance (McCluskey *et al.*, 2010; Keiner *et al.*, 2018). Additionally, a weaker lower body in throwing athletes may overload the upper body (chain) and in turn, cause shoulder injury (Webster, Morris and Galna, 2009; Miller *et al.*, 2018). This demonstrates the importance of including the whole kinetic chain in throwing programs and thus provided motivation for the inclusion of weighted squats in the protocol for this study. However, there were no measured benefits to this inclusion over a four week programme. Although the value of kinetic chain strength and flexibility is well accepted (for TP and injury prevention), few studies have evaluated the inclusion of these exercises and there is therefore a huge gap in the research to include lower limb and kinetic chain factors into future research and evaluate its contribution to TP more holistically (Ellenbecker and Aoki, 2020).

Non-dominant pectoralis minor length was associated with accuracy in amateur cricket players (Ahmed, Brown and Gray, 2020). This confirms that musculoskeletal factors can influence TA in addition to cognitive skill acquisition factors, but both pectoralis minor length and glenohumeral internal rotation range were not measured in the current study due to issues with the testing procedure used by a new physiotherapist during the follow-up tests. There were no significant changes in TA in this study which may be in part due to very little change in musculoskeletal variables.

Specific rotator cuff and shoulder strength and power exercises have been correlated with superior TS in a variety of other overhead sports (Freeston *et al.*, 2016). Evidence shows that muscle hypertrophy and adaptations begin to occur with resistance training over a 6–8-week period (Abe *et al.*, 2000; Faigenbaum *et al.*, 2015) nevertheless, a systematic review showed that these effective programs were conducted over a minimum of four weeks, done 2-3 times per week and used various resistance equipment, including body weight, bands and weighted balls (Martinez-Garcia *et al.*, 2021). The current study included exercises that utilized body weight, resistance bands and weighted medicine balls, twice a week, over a four week period. Although the protocol is within the same parameters of what has previously been found to be effective, perhaps the changes over a four week period were not significant due to an already high functioning group of athletes (high mean KJOC scores).

Pain and injury

The prevalence of musculoskeletal shoulder pain in adolescent male water polo players was reported to be 51% in a 12 month period (Ellapen *et al.*, 2013). The prevalence of reported shoulder pain in this study was 34% over the four week period.

Data analysis showed that there was no significant difference between groups for training load or pain prevalence (p=0.469) in the current study. Pain prevalence decreased from week one (67%) to week four (1%), for both groups. Prior to week one, the water polo athletes attended a four day training camp, which may have influenced reported pain for this week due to a sudden increase in training load (swimming, throwing and passing) owing to it taking place after school holiday break. In week four, the senior (first team) athletes attended a tournament, but this did not appear to have an impact on reported pain as has been noted previously in other adolescent water polo studies (Tully, 2022). Week four was the last week of the season, where participants had started pre-season rugby and hockey fitness (no contact). On average, participants reported an additional 60-90 minutes of fitness unrelated to water polo (rugby/hockey) during this last week.

Participants, who reported pain over the weeks of the study, reported that the majority of their pain was attributed to throwing, which has previously been demonstrated in an adolescent water polo (Jameson, 2020) and elite female water polo populations (Wheeler *et al.*, 2012). Some athletes reported pain whist swimming and upper body gym, but this was marginal by comparison.

Similar strength and stretching programs were conducted over 6-8 weeks, three times a week, on collegiate and elite swimmers with no effect found on musculoskeletal factors (Lynch *et al.*, 2010; Hibberd *et al.*, 2012). Lynch *et al.*, (2010) however found that the intervention group had less incidences of perceived shoulder pain, therefore possibly showing that the strength program had a protective effect. Although the protocol in this study was similar to these swimming studies, it was conducted over four weeks and done twice a week for 10-15 minutes before practices for convenience and compliance.

4.6 Limitations

This study had several limitations which may have influenced the study outcomes.

The sample size was relatively small and may have lacked statistical power to detect meaningful differences. Additionally, the range of age groups may have also masked potential improvements which may be specific to certain age groups.

The same strength Therabands and weighted balls were used for all boys across all age groups for convenience. A variety of bands and weights should be trialled. Limitations in a swimming study noted that allowing participants to select their own band strength potentially led to an insufficient load (resistance) being applied in order to achieve musculoskeletal adaptation (Hibberd *et al.*, 2012). The above mentioned studies included more general upper body and leg strength so this may be a valuable edit to the current program. The individual shoulder banded exercises could be condensed into fewer more general exercises in order to make time provision for the lower limb exercises and still keep the conditioning program to around 10-15 minute duration.

Despite the lack of significant differences between the intervention group and the control group, our study provides valuable insights into the potential effects of a four week intervention program on TP and injury risk in adolescent male water polo players. Unfortunately due to COVID restrictions and a shorter water polo season, the intended six week protocol had to be shortened to four weeks (discussed in COVID chapter). There is a cricket study that indicates that four weeks can be effective in making positive musculoskeletal and performance changes for bowling velocity (Maker and Taliep, 2021). While the current study had a similar duration the mode was different as focusing on the lower limb, core and plyometric exercises. School water polo in South Africa is seasonal (two three month periods), so perhaps there is a need to adapt this protocol to include a preseason intervention over a 6 to 8 week period and reassess its effectiveness over this longer duration.

Further research with larger sample sizes, longer intervention durations, and a broader kinetic chain approach could be used to investigate the influence of exercise interventions in this population.

4.7 Conclusion

This study adds to the existing literature by providing insights into the potential effects of a short term program aimed at improving TP and reducing injury risk. A four week conditioning programme conducted twice a week for 10-15 minutes prior to practice did not positively influence the musculoskeletal variables, shoulder pain or throwing performance.

This study did find that the compliance with the session time, the weekly frequency and the fact that it was part of the water polo practice was excellent. This information could be used when designing future in-season conditioning programmes.

Furthermore, this study may assist in the future development of evidence based interventions that can be implemented by water polo coaches and medical staff to optimize the performance and well-being of adolescent male players.

Chapter 5
Summary and practical implications

5.1 Summary

There were three main objectives of this study. Firstly, it aimed to investigate the musculoskeletal parameters associated with TP. Secondly, it aimed to evaluate the effects of an in-season exercise intervention program on both shoulder injuries and TP among male adolescent water polo players.

This study provided some novel findings with regards to musculoskeletal factors which contribute to the TP in water polo players and this can be added to existing literature in other overhead throwing sports (McCluskey *et al.*, 2010; Ferragut *et al.*, 2011; Platanou and Veramenti, 2011; Ortega-becerra, Pareja-blanco and Jiménez-reyes, 2017; Noronha *et al.*, 2022).

Factors associated with throwing performance:

Five of the 15 variables correlated with TP. The factors which were found to influence TS are: age, posterior capsule length, pectoralis minor length and glenohumeral internal rotation strength at 90°. The CKCUEST correlated with TA. This highlights the importance of having a well-balanced program that covers strength of the rotator cuff, scapula and rotator cuff stability and flexibility in this water polo population.

Older athletes showed greater TS than their younger counterparts, which could be attributed to playing experience as well as general size and strength of the individual.

Specific stretching for the posterior capsule and pectoralis minor should be included in a conditioning program as an increase in length in these variables was associated with an increase in TS in this population. A shorted pectoralis minor has been previously associated with altered scapula mechanics and in turn a decrease in TA (Borstad and Ludewig, 2013). Posterior shoulder tightness needs to be assessed on an individual basis and so should not be prescribed a generalised exercise.

Strengthening of the glenohumeral internal rotators should be done at 90° due to the association with improved TS. This is supported by studies investigating elite female (Platanou and Veramenti, 2011) and youth (Ramalheira *et al.*, 2022) water polo players, and elite male cricket players (Djanis, 2021)

The CKCUEST was associated with TA. Throwing accuracy has numerous contributing factors and cannot be attributed to musculoskeletal variables alone; however superior stability and proprioception correlated with TA and should be prioritised in water polo training programs.

TP and injury in athletes involve numerous variables, with some identified as more pertinent than others. The significance of the kinetic chain in throwing athletes, including water polo players, has been widely acknowledged and discussed (McCluskey *et al.*, 2010; Ferragut *et al.*, 2011; Platanou and Veramenti, 2011; Ortega-becerra, Pareja-blanco and Jiménez-reyes, 2017; Noronha *et al.*, 2022). While certain musculoskeletal indicators of performance were identified, it is important to consider the shoulder within the broader context of the kinetic chain. Subsequent research should explore these factors in relation to performance.

Influence of the in-season conditioning on musculoskeletal risk factors, injury risk and TP:

A four week conditioning programme conducted twice a week for 10-15 minutes prior to practice did not positively influence the musculoskeletal variables, shoulder pain or TP. The athletes were tracked for a four week study period during which the intervention group took part in the conditioning program twice a week and the control group only did their pool based water polo training. The whole study group was asked to monitor pain and specific training loads with a google form sent to their phone at the end of each of the four weeks. Although there were no significant differences in shoulder injury incidence, self-reported pain or TP between groups, our results indicate that self-reported pain is indeed a noteworthy concern among adolescent male water polo players. Reported pain in adolescents over a 12 month period has previously been found to be 51% (Ellapen *et al.*, 2013) with this study finding a prevalence of 34% of self-reported shoulder pain over the four week study period. This further emphasises the need for evidence-based interventions in water polo.

Coaches and trainers should prioritize the implementation of injury prevention strategies, including appropriate warm-up, cool-down, and stretching routines, as well as diligent monitoring of training loads and effective fatigue and recovery management whenever feasible (J. L. Zaremski, Zeppieri and Tripp, 2019). With water polo being a seasonal (summer sport) in South Africa, this is particularly important in adolescent groups where concurrent sports practices occur or sports seasons overlap due to change in season.

The compliance with the session time, the weekly frequency and the fact that it was part of the water polo practice was excellent. This information could be used when designing future in-season conditioning programmes.

5.2 Limitations

This study has potential limitations. Due to the sample size (n = 43) and the significant variables (n = 8) that were used in the multivariance analysis, results should be interpreted with caution due to the limited statistical power drawn from said sample size (Harrell Jr, Lee and Mark, 1996). The intention was to have a sample group of at least 50 subjects, but due to strict COVID restrictions at one of the schools, additional athletes could not be tested.

The study duration was reduced due to COVID restrictions and a shorter water polo season; the intended six week protocol had to be shortened to four weeks (discussed in COVID chapter). A 6-8 week intervention period should be tested in the future.

Contamination amongst the sample may have occurred. The study participants trained in groups and therefore there was a lack of blinding between them. This may have influenced their responses in the self-reported questionnaires on load and function.

Pectoralis minor length and glenohumeral internal rotation range were not factored into the data analysis for chapter 4 due to concerns with the testing position employed during follow-up assessments by the Physiotherapist. Regrettably, the original tester was unavailable at short notice. Despite prior training, inconsistencies were identified in the gathered data.

Being in a school environment, an in-seasoning conditioning program has numerous difficulties due to players of different ages and playing levels being involved. Further, it is hard to control for external variables such as training loads (other sports or activities), recovery, compliance to medical or coaching advice and other school commitments.

Additionally, the participants of this study were adolescent male water polo players and therefore these findings may not be generalisable across all ages and playing levels and this should be considered in future research. The findings can however help to tailor training plans for this specific sample group.

5.3 Clinical implications

The findings of this study suggest that the assessment of musculoskeletal variables prior to the sports season may serve as a predictive tool for TP. By targeted interventions to improve these variables, there is potential to enhance overall performance. Specifically, incorporating stretching exercises to improve the lengths of the pectoralis minor and posterior capsule may prove beneficial. Additionally, focusing on strengthening the glenohumeral internal rotators at 90° of abduction and in functional throwing positions could potentially enhance TS. Implementing preseason rehabilitation programs that emphasise scapula stability and subsequently enhance CKCUEST scores may further contribute to improve TA. Table 5-1 presents suggested exercises suitable for inclusion in conditioning programs with the goal of targeting TP.

Table 5-1 Exercises for TP in water polo players

Exercise	Purpose	Reference
Banded internal rotation at 90°	Strengthens subscapularis and pectoralis group which is correlated with TS.	Freeston *et al.*, (2016)
Push up plus	Strengthens the serratus anterior, pectoralis groups and subscapularis muscle and improves scapular control.	Decker *et al.*, (1999)
4-point kneeling hand slide	Improves neuromuscular control, increase muscle activation and proprioceptive value. Band adds activation of posterior cuff during movement.	Tucker *et al.*, (2011)
Cross body stretch	Posterior shoulder complex stretching maintains flexibility and helps to improve or maintain GH ROM.	McClure *et al.*, (2007)
Pectoralis minor stretch	Maintains shoulder flexibility by stretching the pectoralis minor muscle. This may assist with control of USR during shoulder elevation, and reduce stress on the shoulder during overhead throwing and swimming.	McClure *et al.*, (2007)

TS: Throwing speed, GH ROM: Glenohumeral range of motion, USR: Upward scapula rotation

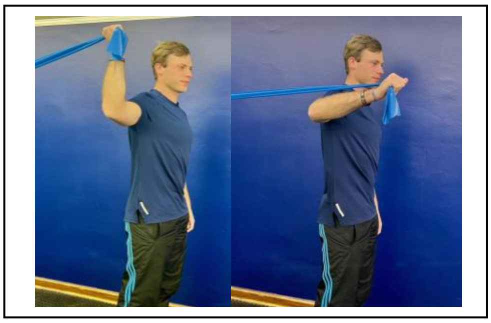

Figure 5-1 Internal rotation at 90°

Figure 5-2 Push up plus

Figure 5-3 4-point kneeling hand slide

Figure 5-4 Cross body stretch

Figure 5-5 Pectoralis minor stretch

The images presented in above figures were captured by the author and depict the recommended exercises to improve throwing performance in an adolescent water polo population. The individuals depicted in the images have provided informed consent for the use of their likeness, including the visibility of their face.

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Appendix I: Ethical approval for studies in this thesis

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

28 September 2021

HREC REF: 543/2021

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 EFFECTS OF A 6-WEEK SHOULDER EXERCISE INTERVENTION ON MUSCULOSKELETAL RISK FACTORS, SHOULDER INJURY AND THROWING PERFORMANCE IN ADOLESCENT MALE WATER POLO PLAYERs. (MASTER'S DEGREE – MRS CANDICE KELLY MACKENZIE)

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: Mrs Candice Mackenzie will also be involved in this study.

Please quote the HREC REF 543/2021 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.

HREC/REF 543/2021sa

Yours sincerely

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

Appendix II: Demographic information collection form

DEMOGRAPHIC INFORMATION COLLECTION FORM

PARTICIPANT CODE: ________________

DATE: ___________

1. Personal Information

Please complete the table below: (circle where appropriate)

Name				
Surname				
Date of Birth				
Age				
School & Team				
Dominant Hand	Left		Right	
Position	Goalkeeper	Defensive specialist	Driver	Two-meter specialist

2. Contact Details

This information is needed to provide feedback to each participant and their guardians at the end of this study. Please complete the table below:

Contact Number	
E-mail Address	

3. Water polo Specific Data

Please show how much times you train during the week on average. (Mark with an "x")

Hours	**0–30min**	**30min–1 hr.**	**1–2 hrs.**	**2–3 hrs.**	**3-4 hrs.**	**4-5 hrs.**	**5-6 hrs.**	**6-7 hrs.**	**> 7hrs**
Swimming									
Water polo specific									
Upper body strength/ gym									

4. General Health Status

Do you have any of the following? If yes, please indicate the frequency (i.e.: once a week) and the medication you use for the condition.

Condition	Yes	No	Frequency	Medication
Asthma				
Hypertension				
Diabetes				
Epilepsy				
Migraines				
Pins and needles in both arms at the same time				
Dizziness				
Glove like pins and needles or excessively sweaty palms				
Nausea				

5. History of Injury

Please show whether you have picked up any of the following injuries (mark with an "x"). If you answer yes then please complete the rest of the columns.

Injury	Yes	No	Which side?		Date of Injury	Do you still have the injury?	
			Left	Right		Yes	No
Headache							
Whiplash							
Shoulder muscle tear							
Neck Injury							
Pain down either or both arms							
"Tennis Elbow"							
Thrower's Shoulder/Impingement							
Upper arm muscle tear							
Upper back pain							
Lower back pain							

Appendix III: Kerlan-Jobe orthopaedic clinic shoulder and elbow score questionnaire

KERLAN-JOBE ORTHOPAEDIC CLINIC SHOULDER AND ELBOW SCORE

Participant Code: ______________

Please answer the following questions related to your history of injuries to YOUR ARM ONLY:

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)

- o Rest
- o Therapy
- o Surgery (please give a description)________________________

Please describe your level of competition in your current sport: (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:

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

Instructions to athletes:

*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 or 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 *No endurance*
(Changed playing position) *limitation in competition*

9. How much has your control (passing, 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 IV: Detailed methodology

Methodology

1.1 Overview

The schools and groups were chosen for convenience purposed for the student researcher. The school that was to be used as the control group, had poor response to the parental consent, so we then decided to use only one school, increase the number of subjects from just one school. Thereafter they were randomly divided into two groups, one group being the intervention group and the other, the control group.

All participants underwent a standardized musculoskeletal pre-screening and throwing performance assessment. For a period of four weeks during the water polo season, the intervention group performed a prescribed set of supervised and standardized shoulder exercises (exercises to reduce identified risk factors and improve performance) in conjunction with their normal training. The exercises aimed to improve strength imbalances, retrain scapular stability and improve core strength. The control group continued with their usual pool-based water polo training. All participants were asked not to partake in any form of structured exercise routine for the duration of the four weeks (outside of the standard water polo pool-based training that both groups usually do). During the four week intervention, participants were sent an injury monitoring questionnaire on a weekly basis to monitor shoulder pain, function and compliance. At the completion of the four weeks, all participants repeated the musculoskeletal screening assessment. Both sets of clinical and performance tests and the exercise intervention, were conducted by qualified Physiotherapists.

It was agreed that if the conditioning program was found to be effective, it would be given to the control group after the study was completed.

1.2 Participants

a) Recruitment
Ethical approval was obtained from the Human Ethics Research Committee, Faculty of Health Sciences, University of Cape Town (Appendix I: Ethical approval for studies in this thesis). St Andrew's College in Grahamstown was approached due to the proximity of the clinical rehabilitation centre to be used for the 4 week intervention programme. The head of sport and headmaster were contacted for recruitment, which took place at the start of pre-season. Players were informed that their participation in the study was voluntary.

b) Inclusion Criteria
Participants between 14 and 18 years of age were included if they played for the U15, U16 A or B team or 1st, 2nd or 3rd team water polo in the open category and trained at least twice (net) per week in the pool.

c) Exclusion Criteria
Players who had an existing shoulder injury at the time of the pre-season screening were excluded from the study. A shoulder injury was defined as a limitation to participate in training or matches due to shoulder symptoms.

d) Sample Size Determination

A sample size that would yield sufficient statistical power was obtained by using previous data from studies which measured the effect of shoulder pain on scapula upward rotation (Myers *et al.*, 2005; Giles and Musa, 2008), GH internal and external rotation range of motion (Green *et al.*, 2019), strength of scapula stabilisers (serratus anterior)(Cools *et al.*, 2010) and strength of GH internal and external rotators. Sample size was calculated using a small meaningful difference of 2 units, and a standard deviation of 3 units (effect size *d* = 0.7). With statistical significance accepted as $p < 0.05$, a group of 29 participants will provide 80% statistical power for strength of GH internal and external rotators respectively.

1.3 COVID-19 safety protocols

St Andrew's College had strict COVID-19 policies in place at the time of testing. We therefore followed and respected the schools policy. In addition to this, did daily screening of any research assistants going onto the school property. Equipment was sterilised between participants and gloves and masks were worn at all times. Social distancing of participants and researchers was adhered to when possible.

With some of the testing having been done in the pool, without masks, it is good to note that there was no evidence that COVID-19 transmission through water at the time of testing (Hill, Nikolaidis and Knechtle, 2020). In addition each player was tested individually.

1.4 Calibration of equipment

1.4.1 The dynamometer was fully charged before and between testing sessions and was in best working order. Settings were checked and were in Nm, calibrated to zero and known weights tested. No calibration adjustments were made.

1.4.2 The radar gun was fully charged before and between testing sessions and was in best working order. Settings were checked and were in km/hr. No calibration adjustments were necessary.

1.4.3 The digital inclinometers batteries were changed every four hours and the unit was calibrated to zero on a flat surface between each measurement. Accuracy was tested using know angles and no adjustments were necessary. Accuracy testing was repeated three times per testing day.

1.5 Study Procedure

a) Informed Consent

The informed consent and ascent form (Appendix IX: Informed consent form: Chapter 3 & 4 and Appendix X: Informed assent form: Chapter 3 & 4) states that ethical approval for this study had been granted and that participation in the study was voluntary. The testing procedures and the risk, benefits and significance of the study were thoroughly explained to participants and their parent or guardian. The participants and parent/guardians were informed of the right to withdraw from the study at any time and that confidentiality would be maintained.

b) Demographic Information

Participants were requested to complete a questionnaire to obtain basic demographic data, training and competition history

Appendix II: Demographic information collection form). This information was obtained from each participant at the time of screening.

c) Anthropometric Measurements

The standing height (cm), seated height (cm) and weight (kg) of each participant was measured at the pre-season screening. These measurements were used to calculate maturity using Peak Height Velocity (PHV) (Mirwald *et al.*, 2001)(Appendix XI: Data collection form).

d) Pre-Season Screening

1) *Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow Score Questionnaire* (Appendix III: Kerlan-Jobe orthopaedic clinic shoulder and elbow score questionnaire)

The KJOC questionnaire is a self-administered 10 question questionnaire that measures function and athletic performance in the overhead athlete. The KJOC questionnaire is a valid (r = 0.84 – 0.86) and reliable (ICC = 0.88) measure of shoulder and elbow function in overhead athletes (Alberta *et al*., 2010).

The questionnaire is divided into three sections. Section one (four questions) addresses function and athletic performance. The second section (five questions) measures self-reported symptoms related to the upper extremity and the third section (one question) addresses interpersonal relationships with regards to performance. Each question is answered using a Visual Analogue Scale (VAS). The left hand side of the scale reflects the lowest possible function or performance level and maximum severity of symptoms and the right hand side reflects the highest or the very minimum symptoms experienced.

2) Clinical Tests

a. Hawkins-Kennedy

The Hawkins Kennedy Test is used to assess subacromial shoulder impingement. This test was done with the participant in a stable, seated position with their feet on the ground. The shoulder being tested was stabilised gently by the examiner by applying a gently downward pressure with their hand. The participants arm was then positioned freely over the examiners arm. The examiner then performed GH internal rotation with the participants shoulder in 90° GH flexion (Cools, Cambier and Witvrouw, 2008). The participant confirmed any pain with a yes/no answer. A single test was conducted on each side, with the non-dominant arm being tested first. This test has a sensitivity of 79% and a specificity of 59% (Hegedus *et al.*, 2008).

b. Neer's

The Neer's test is done to assess both subacromial and internal shoulder impingement. The test was done with the participant in a stable, seated position with their feet on the ground. The scapula being tested was stabilised by the examiner to prevent any scapula rotation or elevation. The examiner then moved the participants arm into full GH flexion. The participant confirmed any pain with a yes/no answer. If the participant answers yes, another question asking for the location of pain was asked. Anterior pain is indicative of subacromial impingement and posterior pain is indicative of internal impingement. A single test was conducted on each side, with the non-dominant arm being tested first (Cools, Cambier and Witvrouw, 2008) . This test has a sensitivity of 79% and a specificity of 53% (Hegedus *et al.*, 2008).

c. Jobe's

The Jobe's test is done to assess the integrity of the supraspinatus tendon and potential anterior shoulder impingement. This test was done with the participant in the standing position with their feet shoulder width apart, with both shoulders in 90° GH elevation, in the scapula plane, and full GH internal rotation (empty can position). The participant was asked to do GH flexion simultaneously on both arms and the examiner resisted this movement with a downwards force. The participant confirmed any pain with a yes/no answer. The test was repeated using the same protocol as above, with both shoulders in 90° GH elevation, in the scapula plane, and full GH external rotation (full can position). Each component of this test was completed once, making a note of any pain and the affected side or sides. This test must be interpreted in combination with the other impingement tests (Hegedus *et al.*, 2008) as there is limited evidence for the sensitivity, specificity and accuracy of this test.

3) *Scapula Upward rotation*

The protocol for scapula upward rotation described by Watson *et al*. (2005) was used in this study. Participants will be asked to stand in a relaxed, balanced stance with their feet shoulder width apart, arms at their sides, elbows extended and wrists in neutral. A manually operated inclinometer (Digi-pas DWL80E, Digipas Technologies, Inc, Dundee, England) was aligned along the spine of the scapula. Participants were then instructed to lift their arm into abduction and stop at 45°, 90° and 135° degrees as well as at their end of range. The degree of scapula upward rotation was documented at each one of these positions. A wall chart clearly showing these ranges was used for consistency. There is good to excellent intrarater reliability (ICC = 0.89 – 0.96) and good to excellent validity for the use of this method in assessing scapula upward rotation (Johnson, McClure, & Karduna, 2001; Watson et al., 2005)

4) *Internal & External Shoulder ROM*

Glenohumeral internal and external rotation was measured by using a goniometer as described by Kolber and Hanney (2012) and reviewed by Cools *et al*. (2014). GHJ rotation measurements were taken with the patient in the supine position. The arm to be tested was positioned with the shoulder at 90° abduction, 90° elbow flexion and the wrist in neutral. Neutral horizontal positioning (humerus in line with the acromion process) was ensured by putting a rolled towel underneath the humerus. The participant was then asked to rotate the shoulder to full, pain/discomfort free external rotation. The participant was instructed not to lift their lower back during testing. Once end range was achieved, the measurement was recorded. Once external rotation had been measured, the participant then moved the shoulder back to the starting position and then followed the same procedure for internal rotation. The olecranon was used as the instantaneous axis of rotation, while the stable arm of the goniometer was perpendicular to the ground and the moving arm, parallel to the shaft of the ulna. Measurements were taken twice for each range on both shoulders and an average score was recorded. Kolber and Hanney (2012) found excellent reliability (ICC = 0.94 – 0.98) and validity (ICC values ≥ 0.85) for the use of a goniometer to measure shoulder

ROM. Emphasis must be placed on recording and standardising the testing position (Kolber and Mdt, 2012).

5) *Strength measures*

a. *GHJ internal and external rotation strength (isometric)*

Isometric strength was assessed using a hand-held dynamometer (HHD) (MicroFET 2 Hoggan Scientific, LCC, Salt Lake, Utah, USA).

To prepare participants for the strength component of the screening protocol and to warm up their shoulders beforehand, each participant performed three repetitions at 70% maximum voluntary isometric contraction of the glenohumeral internal and external rotators, upper and lower trapezius and serratus anterior.

The testing was done in an upright seated position against a stable back. The starting position of the arm was in 90° GHJ abduction, 90° GH external rotation and 90° elbow flexion (Tyler *et al.*, 2005). The HHD was placed 2 cm proximal to the ulnar styloid on the dorsal (ER strength) or ventral forearm (IR strength). Two repetitions of 3 seconds of maximal contractions of voluntary effort were performed on each arm and an average recorded. Stabilisation of the upper arm, shoulder, scapula, and trunk were provided by manual fixation by the examiner if necessary.

The participants followed the same procedure a second time, but had the shoulder in 135° abduction and elbow at 45°, in order to mimic the range in which the participant would likely take a water polo shot or make a pass.

b. *Scapula Muscle Strength*

The scapula stabilisers will be measured using a protocol discussed by Cools *et al.* (2010), in a study that looked at scapulothoracic position in adolescent tennis players.

i. Serratus Anterior

The participant was in the supine position with the shoulder at 90° forward flexion and the elbow in full extension. The HHD was placed in the palm of the hand of the arm that was tested. The investigator applied downward force into the participant's palm while the participant was instructed to perform scapula protraction while maintaining elbow extension.

ii. Upper Trapezius

The participant was in the sitting position with their arms securely at their sides. The investigator stood behind the participant and will place the HHD over the superior aspect of the scapula and apply a downward force in the direction of scapula depression. The participant was instructed to elevate the scapula upwards in order to resist the downward force of the HHD.

iii. Lower Trapezius

The participant was in the prone position with the shoulder in 145° of abduction and full external rotation. The investigator stood on the side of the arm being tested. The HHD was placed at the distal ⅓ of the lateral aspect of the radius. The participant was asked to raise their arm upwards, as the investigator applied a downward force with the HHD.

Hayes, Walton, Szomor and Murrell (2002), found there to be excellent interrater (ICC = 0.79 – 0.92) and intrarater (ICC = 0.79 – 0.96) reliability for internal and external rotation (Hayes *et al.*, 2002). Cools *et al*. (2014) found there to be both excellent interrater and intrarater reliability for all tests described above (ICC = 0.93 – 0.99). Roy *et al*. (2009) found HDD to be a valid tool to use for isometric muscle testing in the shoulder (Roy *et al.*, 2009).

6) *Length measures*

   a. *Pectoralis Minor Length*

Pectoralis Minor length (PML) was measured using a tape measure with the participant in a supine position with the elbows extended. Prior to measurement, two anatomical landmarks were marked in skin pencil at the medial inferior angle of the coracoid process and another one just lateral to the sternocostal junction at the inferior aspect of the fourth rib (Higson *et al.*, 2018). The distance between these two landmarks was measured with a calliper and the distance is indicative of PML. The non-dominant arm was measured first and then the dominant arm followed. Both sides were done twice and an average obtained for each side. The participant was asked to stand up between each measurement. A Pectoralis Minor index (PMI) = (average PM length in cm/height in cm) x 100) was developed in order to normalise participants' variability in height (Borstad and Ludewig, 2013). Therefore the PML is displayed at a percentage of the participants' height.

The original testing procedure by Borstad *et al*. (2008), was adapted by Cools *et al*.(2010), to have the participant in lying position to negate postural adaptations influencing the measurement and will be used this study (Borstad, 2008; Cools *et al.*, 2010). Borstad (2008) found that using a tape measure to measure PML is a valid tool. Struyf *et al*. (2011) found that this PML protocol measurement has poor to moderate interrater reliability but good to excellent intrarater reliability (Struyf *et al.*, 2011).

   b. *Posterior Shoulder Tightness*

The participant lay in the supine position with their arms in neutral at their side. An inclinometer was attached to the participants' humerus with a Velcro strap slightly above the lateral epicondyle and perpendicular to the humeral shaft. The participant was asked to move their arm into 90° forward flexion with 90° elbow flexion. The inclinometer was set to 0° to the vertical. The tester stood beside the table of the shoulder to be measured (non-dominant side first) and the participant was asked to retract their scapula maximally. The tester then placed one hand under the scapula and pressed their thenar eminence against the lateral border of the scapula, to stabilise the scapula in the maximally retracted position for the duration of the test. The tester then used the other hand to passively move the participants arm to end range horizontal adduction while maintaining neutral humeral rotation. The reading on the inclinometer was noted. Each arm was measured twice times and an average for each arm was obtained. This protocol has a good intrarater reliability (ICC = 0.91) and construct validity for measuring posterior shoulder tightness (Myers *et al.*, 2007).

7) *Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST)*
The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) is a performance test that provides quantitative data (score) for an upper extremity task in closed kinetic chain (Tucci *et al.*, 2014).

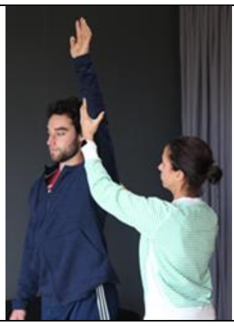
The test was conducted with participants in the push-up position, with their backs straight and parallel to the floor. Their hands were placed on two markers that were stuck to the floor 91.44cm (36 in) apart. For 15 seconds, the participant lifted the one hand and touched the weight bearing hand, alternating hands, as many times as they could in 15 seconds. After the instructions, the participant was allowed to do a few repetitions of a familiarisation task of hand touches. The test was repeated three times (with a rest period of 45 seconds between each repetition) and two scores were given; an average touch score (over the three trials), a normalised score (acquired by dividing the number of touches by the participant height), and a power score (multiplying the average number of touches by 68% of participants body weight (in kg) and then dividing by 15 (Tucci *et al.*, 2014).

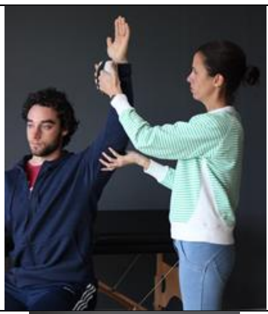
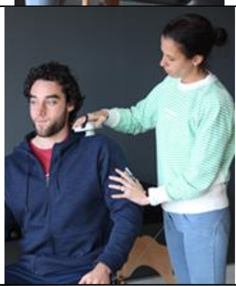
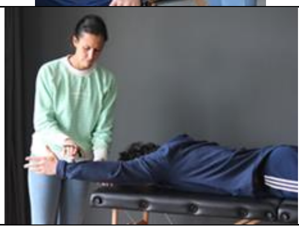
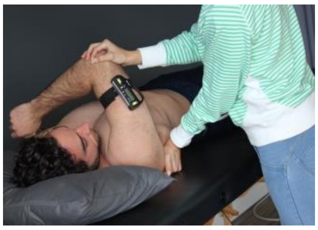
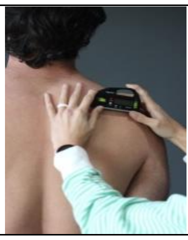
In adolescents, the intersession reliability of the average touches score, normalised score and power score were shown to be 0.68, 0.68 and 0.87 respectively (de Oliveira *et al.*, 2017).

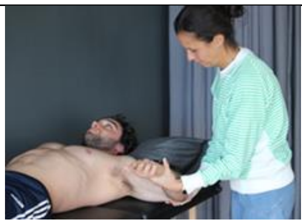
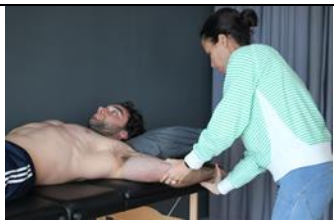
8) *Throwing Performance*
   a. Throwing speed
      Throwing speed was be measured using a cordless radar gun (stalker Pro, Applied concepts Inc, Texas, USA) as previously described by Ferragut *et al.* (2011). Discussed and described in detail in Chapter 3.3.2.3

   b. Throwing accuracy
      Throwing accuracy has been previously described by discussed and described in detail in Chapter 3.3.2.3

Appendix V: Musculoskeletal testing positions

Hawkin's-Kennedy (Pain: Yes/No)		Examiner stabilises scapula. Participant places arm over examiners forearm. Examiner performs passive GHJ IR in 90° GHJ flexion.	Hegedus (2007)
Neer's (Pain: Yes/No)		Examiner stabilises participant's scapula with one hand and raises the participants arm passively into full flexion with other hand.	
Jobe's Empty Can (Pain: Yes/No) Jobe's Full Can (Pain: Yes/No)	 	Arm at 90° GHJ elevation. Examiner performs downward force resisting more GHJ elevation to participants arm. Thumb down position (IR) and then repeated thumb up (ER).	Hegedus (2007)
External Rotation Strength (N)		Seated with arm in 90° GHJ abduction, 90° GHJ ER and 90° elbow flexion. Participant directed to take arm backwards against dynamometer.	Hayes, Walton, Szomor & Murrell (2002)
Internal Rotation Strength at 90° (N)		Seated with arm in 90° GHJ abduction, 90° GHJ ER and 90° elbow flexion. Participant directed to take arm forwards against dynamometer.	Hayes, Walton, Szomor & Murrell (2002)

Internal Rotation Strength at 135° (N)		Seated with arm in 135° GHJ abduction, 90° GHJ ER and 110° elbow flexion. Participant directed to take arm forwards against dynamometer.	Novel test
Serratus Anterior Strength (N)		Supine, 90° GHJ flexion, elbow extension. Participant asked to reach for the ceiling by lifting scapula off the bed.	Cools et al. (2010)
Upper Trapezius Strength (N)		Sitting, arm at side in neutral GHJ rotation. Participant instructed to elevate shoulder.	Cools et al. (2010)
Lower Trapezius Strength (N)		Prone, 145° GHJ elevation and full ER (thumb up). Participant requested to raise thumb to ceiling.	Cools et al. (2010)
Pectoralis Minor Length (cm)		Supine, arms at side in neutral GHJ rotation and full elbow extension. Measure distance between coracoid process and 4^{th} rib.	Struyf et al. (2014)
Posterior Shoulder Capsule Flexibility (°)		Supine with 90° GHJ abduction and elbow flexion. Examiner stabilises scapula and passively takes shoulder into horizontal adduction.	Myers et al. (2007)
Upward Scapula Rotation (°)		Standing and measure scapula upward rotation at 0°, 45°, 90°, 135° and 180° GHJ abduction.	Johnson, McClure & Karduna (2001).

Internal Rotation Range (^{o})		Supine, shoulder at 90^{o} abduction and elbow flexion. Humerus is stabilised in neutral. Participant instructed to internally rotate.	Kolber & Hanney
External Rotation Range (^{o})		Supine, shoulder at 90^{o} abduction and elbow flexion. Humerus is stabilised in neutral. Participant instructed to externally rotate.	Kolber & Hanney
Closed Kinetic Chain Upper Extremity Stability Test (Total Number)		High plank position with hands placed on markers 91.4cm apart. Alternate hand touches for 15 seconds. Total touch score documented, repeated 3 times, with 45 second rest between trials.	De Olivieria et al (2017)

*The images presented in above figure were captured by the author and depict musculoskeletal testing positions used in this thesis. The individuals depicted in the images have provided informed consent for the use of their likeness, including the visibility of their faces.

Appendix VI: All musculoskeletal variables and their correlation with speed and accuracy (bivariate analysis)

Throwing Speed **Variable**	**Coefficient**	**95% CI**	**p Value**
Anthropometric variables			
Mass	0.103	-0.041 – 0.249	0.157
Age 15	8.837	4.009 – 13.665	0.001
Age 16	9.362	4.863 – 13.861	0.000
Age 17	9.950	4.754 – 15.145	0.00
PHV	-2.184	-4.849 – 0.480	0.105
KJOC	-0.079	-0.333 – 0.175	0.532
Musculoskeletal variables			
PSC	0.459	0.16 - 0.75	0.003
Pec Length	2.353	1.224 – 3.482	0.000
USR 0°	0.099	-0.227 – 0.425	0.543
USR 45°	0.120	-0.239 – 0.480	0.504
USR 90°	-0.112	-0.770 – 0.546	0.733
USR 135°	0.094	-0.235 – 0.423	0.567
USR 180°	0.064	-0.273 – 0.403	0.701
GHERR	0.094	-0.079 – 0.268	0.279
GHIRR	-0.142	-0.340 – 0.055	0.154
GHIRS at 90°	0.064	0.032 – 0.096	0.000
Functional throwing range at 135°	0.051	0.020 – 0.081	0.002
ER Strength	0.072	0.012 – 0.132	0.018
LT strength	0.102	0.008 – 0.195	0.033
SA Strength	0.007	-0.014 – 0.028	0.505
UT Strength	-0.002	-0.019 – 0.014	0.784
CKCUEST	0.716	0.217 – 1.214	0.006

Throwing Accuracy Variable	Coefficient	95% CI	p Value
Anthropometric variables			
Mass	-0.001	-0.012 – 0.010	0.846
Age 15	0.265	-0.188 – 0.719	0.252
Age 16	0.017	-0.427 – 0.461	0.940
Age 17	0.157	-0.336 – 0.654	0.529
PHV	-0.073	-0.287 – 0.140	0.500
KJOC	-0.017	-0.038 - 0.002	0.085
Musculoskeletal variables			
PSC	0.005	-0.020 - 0.030	0.687
Pec Length	0.026	-0.076 – 0.129	0.613
USR 0°	0.001	-0.024 - 0.026	0.937
USR 90°	-0.004	-0.055 - 0.046	0.870
USR 45°	-0.000	-0.028 – 0.027	0.952
USR 135°	0.006	-0.018 - 0.032	0.608
USR 180°	0.009	-0.016 - 0.035	0.455
GHIRR	0.000	-0.002 – 0.003	0.932
GHERR	0.012	-0.028 – 0.003	0.136
GHIRS at 90°	0.000	-0.002 – 0.003	0.932
Functional throwing range 135°	-0.000	-0.003 - 0.002	0.687
ER strength	0.003	-0.001 - 0.008	0.227
LT strength	0.000	-0.007 - 0.007	0.983
SA strength	0.000	-0.001 - 0.001	0.874
UT strength	-0.000	-0.002 - 0.000	0.294
CKCUEST	0.012	0.001 - 0.023	0.030

PHV: Peak height velocity, KJOC: Kerlan-Jobe Orthopedic Clinic shoulder and elbow, PSC: Posterior shoulder capsule, USR: Upward scapula rotation, GHIRS: Glenohumeral internal rotation strength, GHIRR: Glenohumeral internal rotation range, GHERR: Glenohumeral external rotation range, GHERS: Glenohumeral external rotation strength, SA: Serratus anterior, LT: Lower trapezius, UT: Upper trapezius, CKCUEST: Closed kinetic chain upper extremity stability test.

Appendix VII: Injury and load monitoring questionnaire/logbook

Water Polo Shoulder Study

Weekly feedback questionnaire

Please select your name

Choose

Time spent playing sport and training this week

Please fill in the following questions:

Todays date:

Date

yyyy-mm-dd

In the past week, how many minutes (in total) have you spent on water polo swimming?

- 45-60 minutes
- 60-90 minutes
- 90-120 minutes
- 120-160 minutes
- 160 - 180 minutes
- More than180 minutes

In the past week, how many minutes (in total) have you spent on water polo throwing, passing, shooting and skills?

- 45-60 minutes
- 60-90 minutes
- 90-120 minutes
- 120-160 minutes
- 160 - 180 minutes
- More than180 minutes

In the past week, how many minutes (in total) have you spent on swimming (pool) training? ie. minor sport

- 45-60 minutes
- 60-90 minutes
- 90-120 minutes
- 120-160 minutes
- 160 - 180 minutes
- More than180 minutes

In the past week, how many minutes (in total) have you spent on water polo matches?

- ◯ 45-60 minutes
- ◯ 60-90 minutes
- ◯ 90-120 minutes
- ◯ 120-160 minutes
- ◯ 160 - 180 minutes
- ◯ More than180 minutes

In the past week, how many minutes (in total) have you spent on upper body gym work/strength training?

- ◯ 45-60 minutes
- ◯ 60-90 minutes
- ◯ 90-120 minutes
- ◯ 120-160 minutes
- ◯ 160 - 180 minutes
- ◯ More than180 minutes

In the past week, how many minutes (in total) have you spent on something else? Please state what it was and how much time you spent doing it.

Your answer

Shoulder Symptoms

For this section, shoulder pain is described as "a physical complaint or presentation of pain sustained during a match or training, where there is a loss of playing time (training or match) or a modification of activity because of pain".

Have you had any shoulder symptoms in the past week?

- ◯ Yes
- ◯ No

Please specify what you have experienced:

- ◯ No pain
- ◯ Pain but no change in practice and training
- ◯ Pain and had to miss time/adapt training/play in a match and compensate for sore shoulder
- ◯ Pain in your shoulder that bothers you at night time

Which shoulder is sore?

- ◯ Dominant arm
- ◯ Non-dominant arm
- ◯ Both
- ◯ No pain

How painful is your shoulder?

	1	2	3	4	5	6	7	8	9	10	
No Pain	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Worst possible pain

During which activity did your shoulder pain first come on?

- ◯ Throwing
- ◯ Swimming
- ◯ Defending
- ◯ Gym
- ◯ Other

If other, what were you doing when you noticed that your shoulder was sore?

Your answer

Would you like advice on how to manage your shoulder pain?

- ◯ Yes
- ◯ No

Shoulder strength/power

For this section, strength/power is defined as the ability of the body to perform an activity.

In the past week, how much strength/power have you had with passing?

	1	2	3	4	5	6	7	8	9	10	
No strength/power at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most power/strength

In the past week, how much strength/power have you had with shooting?

	1	2	3	4	5	6	7	8	9	10	
No strength/power at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most power/strength

In the past week, how much strength/power have you had with swimming?

	1	2	3	4	5	6	7	8	9	10	
No strength/power at all	○	○	○	○	○	○	○	○	○	○	Most power/strength

In the past week, how much strength/power have you had with defending?

	1	2	3	4	5	6	7	8	9	10	
No strength/power at all	○	○	○	○	○	○	○	○	○	○	Most power/strength

In the past week, how much strength/power have you had with gym?

	1	2	3	4	5	6	7	8	9	10	
No strength/power at all	○	○	○	○	○	○	○	○	○	○	Most power/strength

Appendix VIII: Exercises and explanations

The strength exercises will be set up with repetitions and sets based on guidelines from a meta-analysis that assessed youth resistance training. The guidelines describe a resistance program that is set up with 2-3 sets of 8-15 repetitions with loads between 60% to 80% of the 1 RM, in a youth population (Faigenbaum *et al.*, 2015).

1. **Push-up plus (Serratus Anterior, Subscapularis and Supraspinatus)**
    - Sets: 3
    - Repetitions: 15
    - Load: Body weight, progressed to band
    - Rest between sets: 30 seconds
    - Rationale: To improve Serratus Anterior strength and endurance.

   The Serratus Anterior has a large role in good scapula kinematics (assists in scapula upward rotation and prevents scapula winging) and so it is important that this muscle is strong and working optimally in order to prevent/assist in preventing shoulder injury (Decker *et al.*, 1999). Decker *et al*. (1999) compared various exercises for Serratus Anterior activation and found that the push-up plus and knee push-up were effective in activating the muscle optimally. The exercise was also selected for ease of demonstration and use (Decker *et al.*, 1999).

   PHASE 1: (Week 1)
   Knee push-up plus – This is a modification of the standard push-up plus. The participant begins in prone 4-point kneeling, with the hands shoulder width apart and the chest near the ground. The participant will then extend his elbows and move into a push-up position. Once in a standard push up position, further range will be gained by doing scapula protraction. The participants will then retract the scapula, flex the elbows and return to the starting position.

   PHASE 2: (Week 2 & 3)
   Standard push-up plus – The participant will use exactly the same procedure as Phase 1, except, the starting position will now be in lying and the push-up will happen from the feet and not the knees.

   PHASE 3: (WEEK 4)
   Push-up plus with band: The participant once again uses exactly the same procedure as Phase 1 & 2. He will now however have a Theraband across the back of his upper back with each end secured in one hand. The movement will be performed against the resistance of the band.

2. **Standing Scaption (Upper Trapezius)**
   Rationale: To improve the upper Trapezius strength and endurance.
   The Trapezius has a large role in good scapula kinematics and so it is important that this muscle is strong and working optimally in order to assist in lowering shoulder injury risk (Decker et al., 1999). The Upper Trapezius plays a large role in scapular elevation and upward rotation. Escamilla et al (2009) found that shoulder abduction (and full external rotation of the shoulder) between 80° and 120° in the scapula plane, showed good recruitment of the Upper Trapezius.

PHASE 1: (Week 1)

- Sets: 3
- Repetitions: 12
- Load: Body weight

Standing Scaption 80° – 120° – The participant stands in a comfortable position. They will fully externally rotate and elevate the shoulder to 80°. Starting at 80°, the participant will raise his arm above this level to 120° and then return to 80°. They should ensure that the eccentric component of this return phase is controlled.

PHASE 2: (Week 2 & 3)

- Sets: 3
- Repetitions: 12
- Load: Light Theraband

The same procedure as phase 1 will be followed and the weight will be increased. The participant will use a Theraband. They will adopt neutral spine, both feet comfortably on the floor, and they will complete the rest of the exercise in exactly the same way.

PHASE 3: (Week 4)

- Sets: 3
- Repetitions: 12
- Load: Theraband (increased resistance if appropriate)

The same procedure at stage 2 will be followed. This time, one foot will be lifted off the floor (held up) for 6 repetitions and then the alternate foot will be lifted off (for the next 6 repetitions). This progression will further challenge the participant's core.

3. Prone Y's (Middle and Lower Trapezius)

Rationale: To improve the middle and lower Trapezius strength and endurance.
Lower Trapezius assists in scapula upward rotation and depression, Middle Trapezius assists in scapula retraction and Upper Trapezius assists in scapula upward rotation and elevation. The "Prone Y" showed high general Trapezius activity (middle and lower Trapezius) at 90° and 135° of horizontal abduction with internal or external rotation. Lower Trapezius showed highest activity between 90° and 180° and Middle Trapezius between 125° and 160°(Escamilla *et al.*, 2009). We have therefore chosen 135° to cover both ranges.

PHASE 1: (Week 1)

- Sets: 3
- Isometric hold maintained for: 20-30 seconds
- Load: Body weight

Prone Y's –The participant will be instructed to lie in prone. They will be shown the "Y position" which for this study will be horizontal abduction at 135°**.** Whilst maintaining neutral spine, the participant will fully externally rotate and abduct both shoulders simultaneously into the “Y position”. They will be instructed to hold this position isometrically.

PHASE 2: (Week 2 & 3)

- Sets: 3
- Repetitions: 12
- Load: Individually suited resistance band

Prone Y’s with resistance band –The participant will follow the same body and equipment set up position as Phase 1. In addition, there will now be an individually suited resistance band attached to the floor. The participant will hold one end of the band in each hand. The movement will begin with the hands on the floor, shoulders fully externally rotated, elbows extended and arms in the “Y position”. The arms will be raised into horizontal abduction against the resistance band, held at the maximum abduction for 2 seconds and then slowly lowered back to the starting point without losing control of the movement. The participant must be able to do the full 12 repetitions correctly with the selected resistance band.

PHASE 3: (Week 4)

- Sets: 3
- Repetitions: 12
- Load: Individually suited Theraband

Prone Pezzi (PP) Y’s with dumbbells – The participant will follow the same body and equipment set up position as for Phase 2. The participant will now hold a suitable dumbbell in each hand to complete the “Y position”. The participant must be able to do the full 12 repetitions correctly with the selected band.

4. External rotation

Rationale: To improve Teres Minor and Infraspinatus strength and endurance. The Teres Minor and Infraspinatus make up the posterior rotator cuff which perform external rotation, abduction, and resist superior and anterior humeral head rotation. This external rotation assists in clearing the humeral head through the coracoacromial arch, minimising subacromial impingement (Escamilla *et al.*, 2009). The posterior cuff also performs an integral function (in its eccentric capacity) of decelerating the shoulder in the follow through of the water polo shot. If this strength is not adequate, it may predispose the person to injury. All of the below exercises have been shown to have high activation of both the Teres Minor and Infraspinatus (Escamilla *et al.*, 2009).

PHASE 1: (Week 1)

- Sets: 3
- Repetitions: 8-10
- Load: Individually suited Theraband

The participant will be positioned comfortably in standing with their upper arm and elbow against the body. The elbow is bent to 90° and then they will be instructed to fully externally rotate the shoulder with the end of a Theraband in each of their hands. Once full external rotation is achieved, they will be instructed to hold the contraction for 2 seconds before slowly returning to the starting position.

PHASE 2: (Week 2 & 3)

- Sets: 3
- Repetitions: 8-10
- Load: Individually suited resistance band

The participant will be in standing upright facing the wall. A resistance band will be attached to the wall at head height. The participant will hold one end of the band in each hand; abduct the shoulders to 90° with the elbows bent to 90°. From this position he will perform a full range external rotation. At full range, the contraction will be held for 2 seconds and then he will return to the starting position in a controlled manner.

PHASE 3: (Week 4)

- Sets: 3
- Repetitions: 8-10
- Load: Individually suited resistance band

The participant and equipment set up will be identical to Phase 2. The participant will add a stability aspect to this exercise by doing it on one foot. Half the repetitions were done on one foot and then feet should be changed after the half way point.

5. **Standing rows (mid)**

- Rationale: Due to the posterior rotator cuff (external rotators) having such an important role in the deceleration of the water polo throw, we have included an additional exercise. High, mid and low rows produced high levels of Teres Minor activation.

PHASE 1: (Week 1)

- Sets: 3
- Repetitions: 8-10
- Load: Individually suited Theraband

The participant will begin this exercise in standing and will grasp the Theraband bilaterally. He will then extend the shoulder whilst flexing the elbows. He may row with the elbows at 45° abduction for mid row.

PHASE 2: (Week 2 & 3)

- Sets: 3
- Repetitions: 8-10
- Load: Individually suited Theraband increased

This follows the same procedure as phase 1. Resistance of the Theraband should be increased.

PHASE 3: (Week 4)

- Sets: 3
- Repetitions: 8-10
- Load: Individually suited Theraband increased and standing on one foot

This follows the same procedure as phase 1 & 2. Resistance of the Theraband should be increased again if possible. The participant will perform this exercise whilst standing on one foot. This will be done in order to challenge the core and whole kinetic chain.

6. **Squat and Slam ball throws**

Rationale: To improve muscle power of the whole body

Based on the NSCA guidelines, 2 sets of 1-5 repetitions, is the optimal number of repetitions for improving muscle power (Baechle and Earle, 2008). Significant performance improvements (throwing velocity and isokinetic strength of the shoulder rotators) were seen in amateur female handball players after taking part in a 6-week medicine ball training program (Raeder, Fernandez-Fernandez and Ferrauti, 2015). To obtain maximal throwing velocity, there has to be optimal coordination and timing of consecutive muscle segments (kinetic chain) in both the upper and lower limbs, with a strong core linking the two, therefore, a squat has been included (McCluskey *et al.*, 2010; Fernandez-fernandez *et al.*, 2013; Raeder, Fernandez-Fernandez and Ferrauti, 2015; Kevin E. Wilk *et al.*, 2016).

PHASE 1: (Week 1)

- Sets: 2
- Repetitions: 1-5
- Load: 10kg slam ball

The participant will be instructed to stand facing a wall, shoulder width apart, with the ball on the floor between his feet. The participant will squat down and pick up the ball with both hands and lift it to belly button level. He will then squat 3 times and will then be instructed to bend his knees and take the ball behind his head, extend his back slightly and then powerfully throw the ball from this position using power from his whole body. This will count as one repetition.

PHASE 2: (Week 2 & 3)

- Sets: 3
- Repetitions: 1-5
- Load: 10 kg slam ball

PHASE 3: (Week 4)

- Sets: 4
- Repetitions: 1-5
- Load: 10kg slam ball

The procedure for Phase 2 and 3 will follow that of Phase 1.

7. **Bird – Dog (Core stability)**

Özekli Mısırlıoğlu, (2018) found that core strength exercises conducted in conjunction with a shoulder rehabilitation program, had a significant positive effect on shoulder strength.

PHASE 1: (Week 1)

- Sets: 3

- Repetitions: 10 - 15
- Load: Body weight, progressed to banded resistance

Rationale: To improve general core strength and stability in a functional position.

The participant begins in 4-point kneeling and finds neutral spine. A simultaneous, but alternate (bilateral) lifting of an arm and leg is initiated. The arm should reach out in front of the participant to just below shoulder height. The leg should kick out directly behind him in a pushing action. The spine should remain stable throughout the movement. The arm and leg should return to the starting position and then the exercise should be repeated with the opposite arm/leg.

PHASE 2: (Week 2 & 3)

- Sets: 3
- Repetitions: 10 - 15
- Load: Body weight with advanced technique

Rationale: To improve general core strength and stability in a functional position.

The procedure from phase 1 will be followed; however the participant will now touch their opposite knee to opposite elbow before returning to the starting position each time. Movement was smooth and well executed.

PHASE 3: (Week 4)

- Sets: 3
- Repetitions: 10 - 15
- Load: Advanced technique in high plank position

Rationale: To improve general core strength and stability in a functional position.

The procedure from phase 1 will be followed; however the participant will now use a high plank position, further challenging the core stability.

8. Posterior capsule stretching

Posterior capsule stretching will only be given to a participant if he is found to have posterior shoulder tightness (PST) or Glenohumeral internal rotation deficit (GIRD). PST and GIRD are thought to contribute to impingement symptoms by increasing glenohumeral contact pressure, causing internal impingement at end range external rotation (Mine *et al.*, 2016). The time guidelines and stretching positions are described by Balaicuis *et al.* (2007).

PHASE 1-3: (Week 1 - 4)

- Sets: 2
- Length of stretch: 60 seconds

Sleeper Stretch – the participant will lie on the side to be stretched with the shoulder in 90° forward flexion resting on a supportive surface. The participant will then passively internally rotate the shoulder using the opposite arm.

Appendix IX: Informed consent form: Chapter 3 & 4

Department of Exercise Science and Sports Medicine

Faculty of Health Sciences

Parent/Guardian Information Sheet

The Effects Of A Six Week Conditioning Program On Musculoskeletal Risk Factors, Shoulder Injury And Throwing Performance In Male Adolescent Water Polo Players In South Africa

Dear Legal Guardian

I am a qualified Physiotherapist and Masters candidate within the Department of Human Biology (Division of Physiological Sciences) at the University of Cape Town. We shall be conducting a study to investigate the effects of a shoulder-specific exercise program on identified factors believed to increase the risk of developing a shoulder injury during your son's water polo career. We will also be investigating whether this program may decrease overall incidence of shoulder injuries in water polo players and potentially improve throwing performance.

All of the data collected in this study will be used to meet the requirements of a MSc (Exercise Science). This study has been granted ethical approval by the Human Research Ethics Committee, Faculty of Health Sciences, University of Cape Town (HREC: 543/2021).

Prior to your son's inclusion in this study, you will be required to thoroughly read, complete and sign this form. By signing the form, you hereby grant consent for your son to partake in this research study.

Why is this study being done?

There is a high incidence of shoulder injury in male adolescent water polo players. It has been proposed that the high incidence of shoulder injuries can be attributed to the amount of swimming and overhead throwing that is involved in water polo. We have therefore developed an exercise routine that will aim at minimising risk factors and improving throwing performance.

Why is my son being asked to take part in this study?

Your son has been asked to take part in this study because;

- He is a male between the ages of 14 and 18.
- He plays water polo.
- He is in the 1st, 2nd, 3rd or U15A/B or U16A/B water polo team.
- He attends a high school in Grahamstown, South Africa.
- He currently does not have any injury that he is receiving treatment for.

How many people will take part in this study?

50 Male water polo players from high schools in Grahamstown will take part in this study for the 2022 water polo season.

How long will this study last?

The physical testing will be done at the start of the season and the intervention will be done during the season and will be completed in six weeks. Your son will be required to attend 2 physical testing sessions. Injury monitoring will be done remotely on a weekly basis.

Will my son be paid to take part in this study?

No.

What will happen if my son decides to participate in this study?

Prior to the start of the season, your son will be asked to fill in a questionnaire about his shoulder with regards to activities of daily living and sport. He will then take part in clinical testing that will cover strength, flexibility, function and an ultrasound measurement of his shoulder. An explanation will be given to your son, explaining fully, the testing procedures to be done. After the initial data is collected, your son will be placed either into an intervention group or a control group. During the season, the intervention group will follow the conditioning protocol being tested in this study, as well as their regular training, whereas the participants in the control group will only do their pool-based regular training.

Injury surveillance will be done for the 6 weeks during the conditioning period. Your son will be required to fill in a questionnaire consisting of 6 questions every week which will address shoulder pain/injury and training load. Questions or concerns regarding the testing will be addressed appropriately.

Your son's participation is voluntary and anonymous and will not have any effect on team selection in any way. He may withdraw at any point if he wishes to do so.

The testing protocol for the study will be described below. Your son will need to wear shorts and a t-shirt for the musculoskeletal testing section, and a swimming costume for the throwing performance section:

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

Your son will be required to complete all sections of this one page questionnaire. This will take approximately five minutes to complete. It covers athletic performance, upper limb symptoms and interpersonal relationship with performance. This is completed at both the beginning and end of the study.

2. **Specific Clinical Musculoskeletal tests**

The following tests will be performed on your son's shoulders in a variety of positions (i.e. standing, sitting or lying). This should take around 20-25 minutes to complete.

a) Range of motion of:
   i) Shoulder blade rotational range of motion
   ii) Range of motion of shoulder joint rotation
b) Strength of the muscles that rotate the shoulders:
   i) Inwards
   ii) Outwards
c) Strength of the shoulder blade stabilisers i.e. muscles
   i) Serratus Anterior
   ii) Lower Trapezius
   iii) Upper Trapezius
d) Length of:
   i) Pectoralis Minor (Front chest muscles)
   ii) Flexibility of the posterior shoulder complex (Back of the shoulder)
e) Shoulder impingement tests (Clinical tests to determine whether there is pain with certain movements)
f) Shoulder stability - Closed Kinetic Chain Upper Extremity Stability Test

3. **Throwing performance**

Throwing speed will involve your son throwing a ball as hard as he can into a set of water polo goals. The shot will be performed in the same manner in which a penalty shot would occur within a water polo game. A radar gun will be used to measure the speed of the shot.

Throwing accuracy will be measured by using a special target net that covers the face of the goals. Points will be awarded differently, based on where the ball hits the target.

4. **Exercise intervention**

Participants who are allocated to the exercise intervention group will be required to perform the specific exercises for approximately 10 minutes, twice a week in the pool area before practices. The intervention is divided into three phases of progression. They will be done under the supervision of the principal investigator or student investigator (Qualified Physiotherapist).

Should your son be randomly placed in the intervention group, he would be expected to do the exercise sessions twice a week for the six week period. If your son is in the control group, he will participate only in normal training during this period.

5. Post intervention testing

This will follow exactly the same procedure as the pre intervention testing described above.

6. Injury Monitoring

A self-reported online questionnaire will be used to monitor any shoulder pain or injury your son sustains during the season. It will also track the amount of training that your son does. The questionnaire will be required to be completed once a week for the six week period. There will be three sections to complete and will take approximately 3 minutes. The first section addresses training load, the second will address any shoulder pain experienced and the third section will address strength/power in performing certain water polo activities. This questionnaire will be sent to your son's phone. All the information will remain strictly confidential at all times.

How long does a testing session last?

As mentioned above, testing sessions will occur once at the start of the season and the second one after the 6 week intervention period has been completed. Each testing session will take approximately 30-45 minutes. The 30-45 minutes will be split between; Musculoskeletal testing - 30 minutes and throwing performance test – 15 minutes (includes warm-up period).

How long does an exercise session last?

If your son is allocated to the exercise group, this will require two 10 minute sessions a week for 6 weeks.

What are the risks of participating in this study?

There are minimal to no risks involved with participating in this study. All tests are tests used regularly in a clinical setting and have been found to be reliable. The throwing performance test holds no more risk than a water polo practise. An adequate warm-up will be given to further minimise any risk of injury. The exercises in the intervention group are safe and all exercise sessions will be conducted under the supervision of/ by a qualified physiotherapist.

Muscle soreness or stiffness in the shoulder or back may occur for a few days after testing and/or the intervention exercises. This is normal and expected response after exercises, especially ones that your son may not have done before. However if you have any concerns, please contact one of the investigators to discuss these concerns.

What are the benefits of taking part in this study?

Your son will receive all of his personal results and the results of this study. He will also have a better understanding of the current shoulder "health" and his possible risk for shoulder pain and/or injury. If the exercise intervention is found to have a beneficial effect on injury or performance, the training programme will be made available to the control group.

What happens if my son chooses not to participate in this study?

Your son's participation in this study is completely voluntary and anonymous and you or your son has the right to withdraw from the study at any time. Your son's participation in this study will not impact his involvement at school water polo or team selection in any way and will not be discussed with coaches or management. All his results will be kept confidential.

What will happen when the study is over?

At the conclusion of this study, the data will be presented as a group. These data will be published (anonymity always maintained) in respective medical journals and made available to you (individual and group data) and your school's medical and coaching team as well (group data). Raw data will be stored in a secure and safe facility/location for 5 years, locked in a filing cabinet, after which it will be shredded.

Who will see the information collected about your son during the study?

Only the principal investigator and supervisors (details listed below) will have access to your son's information during this study. All participant information will be kept confidential by using a coding system for anonymity. Each participant will be allocated a specific code and the details of these codes and participant information will be kept private and confidential and stored in a locked filing cabinet in the student investigators office.

What happens if my son gets hurt taking part in this study?

The research in this study is covered by an insurance policy taken out by the University of Cape Town. This applies to any bodily injury sustained because of taking part in the study. The insurer will pay for all reasonable medical costs required to treat your bodily injury, according to the SA Good Clinical Practice. Guidelines 2006. The insurer will pay without you having to prove that the research was responsible for your bodily injury. You may ask the study investigator for a copy of these guidelines.

The insurer will not pay for harm if, during the study, your son:

- Use medicines or other substances that are not allowed
- Does not follow the investigators instructions
- Does not take reasonable care of himself

If your son is harmed and the insurer pays for the necessary medical costs, usually you will be asked to accept that insurance payment as full settlement of the claim for medical costs.

However, accepting this offer of insurance does not mean you give up the right to make a separate claim for other losses based on negligence, in a South African court.

It is important to follow the investigators instructions and to report straight away if your son experiences any adverse effect from the exercises.

Will there be COVID-19 protocols in place?

The schools COVID-19 policy will be strictly adhered to. In addition to this, we will do daily screening of any research assistants going onto school property. Equipment will be sterilised between participants and gloves and masks will be worn at all times. Social distancing during the intervention sessions will be strictly adhered to.

Who do I speak to (or contact) if I have questions about the study?

If at any time you have any questions or concerns about this study, please feel free to contact me or any of the individuals listed below. Please be assured that all enquiries will remain private and confidential.

Student investigator: **Mrs Kelly Mackenzie**

Physical address: Division of Physiological Sciences

Department of Human Biology

University of Cape Town

Sports Science Institute of South Africa

Boundary Road Newlands

7700

Tel number: 083 388 9862

E-mail: Kelly.mackenzie85@gmail.com

Principal Investigator: **Dr. Janine Gray**

Physical address: Division of Physiological Sciences

Department of Human Biology

University of Cape Town

Sports Science Institute of South Africa

Boundary Road Newlands

7700

Tel number: (021) 650 4557

Fax number: (021) 650 1796

E-mail: janineg@cricket.co.za

Co-supervisor: **Professor Stephen Roche**

Physical address: Division of Orthopaedics

H49 OMB

Groote Schuur Hospital

Observatory 7925

Tel number: (021) 4045108

Fax number: (021) 4472709

E-mail: stephen.roche@uct.ac.za

The UCT's Faculty of Health Sciences Human Research Ethics Committee can be contacted on 021 406 6338 (Prof. Marc Blockman, chair of the committee) in case you have any ethical concerns or questions about your rights or welfare as a participant on this research study.

Parent/Guardian Consent Form

The Effects Of A Six Week Conditioning Program On Musculoskeletal Risk Factors, Shoulder Injury And Throwing Performance In Male Adolescent Water Polo Players In South Africa

I, the undersigned, have been fully informed about the inclusion of my son in the study entitled: **"The Effects Of A Six Week Conditioning Program On Musculoskeletal Risk Factors, Shoulder Injury And Throwing Performance In Male Adolescent Water Polo Players In South Africa"** to be conducted by researchers from the Exercise Science and Sports Medicine Research Unit, Faculty of Health Sciences, University of Cape Town.

Please mark, with an "x", the parts of this study that you consent to participating in:

☐ I consent to my son's participation in the shoulder musculoskeletal screening (pre and post intervention) and throwing performance testing screening (pre and post intervention) to be completed by a UCT research investigator. I understand that it will be necessary for my son to perform a variety of tests as described above and I acknowledge that the testing will be done at "a designated location" and will require around 30-45 minutes of my son's time.

☐ I give consent for him to complete an online survey (that will be sent to his phone) once every week for 6 weeks to monitor any injuries during the season.

☐ Should my son be randomly placed in the intervention group, I consent to him participating in two 10 minute exercise sessions per week, for the duration of six weeks.

☐ I consent to the data collected during pre and post intervention testing (as well as injury monitoring date) for my son to be distributed within the UCT research team for part of the analysis as detailed above.

I have read and understood the Participation Information document and I have had the opportunity to ask questions regarding the procedures and results of these tests.

I am aware that the information obtained during this study will be kept confidential, will only be used for scientific research purposes and that any personal information will not be circulated under any circumstances. I have also been informed about the possible risks of participating in this trial. I do understand that there may not be any personal benefit to my son's participation in the study but that there may be future benefits from the study findings.

I know that I have the right to withdraw my son from the study at any time and without any explanation.

I agree to my son's participation in this study.

______________________	______________________	________________
Signature of Parent	**Full Name (Please Print)**	**Date**
______________________	______________________	________________
Signature of Investigator	**Kelly Mackenzie**	**Date**

Appendix X: Informed assent form: Chapter 3 & 4

Department of Exercise Science and Sports Medicine

Faculty of Health Sciences

Participant Information Sheet

The Effects Of A Six Week Conditioning Program On Musculoskeletal Risk Factors, Shoulder Injury And Throwing Performance In Male Adolescent Water Polo Players In South Africa

Dear Participant

I am a Masters candidate within the Department of Human Biology (Division of Exercise Science and Sports Medicine) at the University of Cape Town. We will be conducting a study to investigate the effects of a shoulder-specific exercise program on identified factors believed to increase the risk of developing a shoulder injury during your water polo career. We will also be investigating whether this program may decrease overall incidence of shoulder injuries in water polo players and potentially improve throwing performance.

All of the data collected in this study will be used to meet the requirements of a MSc (Medicine) Exercise Science. This study has been granted ethical approval by the Human Research Ethics Committee, Faculty of Health Sciences, University of Cape Town (HREC: 543/2021).

Please take time to thoroughly read this form before signing.

Prior to your inclusion within this study, you will be required to complete and sign this form.

Why is this study being done?

There is a high incidence of shoulder injury in male adolescent water polo players. It has been proposed that the high incidence of shoulder injuries can be attributed to the amount of swimming and overhead throwing that is involved in water polo. We have therefore developed an exercise routine that will aim at minimising risk factors and improving throwing performance.

Why am I being asked to take part in this study?

You have been asked to take part in this study because;

- You are a male between the ages of 14 and 18.
- You play water polo.
- You are in the 1st, 2nd, 3rd or U15A/B or U16A/B water polo team.
- You attend a high school in Grahamstown, South Africa.
- You currently do not have any injury that you are receiving treatment for.

How many people will take part in this study?

50 male water polo players from high schools in Grahamstown will take part in this study for the 2022 water polo season.

How long will this study last?

The data will be collected over the 2022 water polo season.

Will I be paid to take part in this study?

No.

What will happen if I participate in this study?

Prior to the start of the seasons training, you will be asked to fill in a questionnaire about your shoulder with regards to activities of daily living and sport. You will then take part in clinical testing that will cover strength, flexibility, function and an ultrasound measurement of your shoulder. An explanation will be given to you, explaining fully, the testing procedures to be done.

After the initial data is collected, during the seasons training, you will be placed either into an intervention group or a control group. The intervention group will follow the strengthening protocol being tested in this study, as well as their regular training, whereas the participants in the control group will only do their regular pool-based water polo training.

Over the six week period, you will be required to fill in a questionnaire consisting of 6 questions every week which will address shoulder pain/injury and training load. Questions or concerns regarding the testing will be addressed appropriately.

Your participation is voluntary and anonymous and will not have any effect on team selection in any way. You may withdraw at any point, should you wish to do so.

The testing protocol for the study will be described below. You will need to wear shorts and a t-shirt for the initial section, and swimming costume for the throwing performance section:

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

   You will be required to complete all sections of this one page questionnaire. This will take approximately five minutes to complete. It covers athletic performance, upper limb symptoms and interpersonal relationship with performance. This is completed at both the beginning and end of the study.

2. Specific Clinical Musculoskeletal tests

The following tests will be performed on your shoulders in a variety of positions (i.e. standing, sitting or lying). This should take around 20-25 minutes to complete.

a) Range of motion of:
   i) Shoulder blade rotational range of motion
   ii) Range of motion of shoulder joint rotation
b) Strength of the muscles that rotate the shoulders:
   i) Inwards
   ii) Outwards
c) Shoulder blade stabilisers i.e. muscles
   i) Serratus Anterior
   ii) Lower Trapezius
   iii) Upper Trapezius
d) Length of:
   i) Pectoralis Minor (Front chest muscles)
   ii) Flexibility of the posterior shoulder complex (Back of the shoulder)
e) Shoulder impingement tests (Clinical tests to determine whether there is pain with certain movements)
f) Shoulder stability - Closed Kinetic Chain Upper Extremity Stability Test
g) Throwing performance (Speed and accuracy)

4. Exercise intervention

Participants who are allocated to the exercise intervention group will be required to perform the specific exercises for approximately 10 minutes, twice a week at the pool area before practice. The intervention is divided into three phases of progression. They will be done under the supervision of the principal investigator or student investigator (Qualified Physiotherapist).

Should you be randomly placed into the intervention group, you would be expected to do the exercise sessions twice a week for the six week period. If you are in the control group, you will participate in your normal training during this period.

3. Injury Monitoring

A self-reported online questionnaire will be used to monitor any shoulder pain or injury you may sustain during the season. It will also track the amount of training that you do. The questionnaire will be required to be completed during the 6 weeks of the intervention. There will be three sections to complete and will take approximately 3 minutes. The first section addresses training load, the second will address any shoulder pain experienced and the third section will address strength/power in performing certain water polo activities. This questionnaire will be sent to your phone.

How long does a testing session last?

As mentioned above, testing sessions will occur once at the start of the season and the second one after the 6 week intervention period has been completed. Each testing session will take approximately 30-45 minutes. The 30-45 minutes will be split between; Musculoskeletal testing - 30 minutes and throwing performance test – 15 minutes (includes warm-up period).

How long does an exercise session last?

If you are allocated to the exercise group, this will require two 10 minute sessions a week for 6 weeks.

What are the risks of participating in this study?

There are minimal to no risks involved with participating in this study. All tests are tests used regularly in a clinical setting and have been found to be reliable. The throwing performance test holds no more risk than a water polo practise. An adequate warm-up will be given to further minimise any risk of injury. The exercises in the intervention group are safe and all exercise sessions will be monitored by a qualified physiotherapist. Muscle soreness or stiffness in the shoulder or back may occur for a few days after testing and/or intervention sessions. This is normal and expected response after exercises, especially ones that you may not have done before but you can report this to the investigator if you are concerned.

What are the benefits of taking part in this study?

You will receive the results of this study. You may gain a better understanding of your current shoulder "health" as well as your possible risk for shoulder pain and/or injury. If the exercise intervention is found to have a beneficial effect on injury or performance, the training programme will be made available to the control group.

What happens if I choose not to participate in this study?

Your participation in this study is completely voluntary and anonymous and you have the right to withdraw from the study at any time. This study will not impact your involvement at school water polo or team selection in any way and will not be discussed with coaches or management.

What will happen when the study is over?

At the conclusion of this study, the data will be presented as a group. This data will be published (anonymity always maintained) in respective medical journals and made available to you (individual and group data) and your school medical and coaching team as well (group data). Raw data will be kept in a locked filing cabinet in a secured facility for 5 years, after which it will be shredded.

Who will see the information collected about you during the study?

Only the principal investigator and supervisors (details listed below) will have access to your information during this study. All participant information will be kept confidential by using a coding system for anonymity. Each participant will be allocated a specific code and the details of these codes and participant information will be held private and confidential and stored in a locked filing cabinet.

What happens if I get hurt taking part in this study?

The risk of getting injured in this research study is very low but the research in this study is covered by an insurance policy taken out by the University of Cape Town. This applies to any bodily injury sustained as a result of taking part in the study. The insurer will pay for all reasonable medical costs required to treat your bodily injury, according to the SA Good Clinical Practice Guidelines 2006. The insurer will pay without you having to prove that the research was responsible for your bodily injury. You may ask the study investigator for a copy of these guidelines.

The insurer will not pay for harm if, during the study, you:

- Use medicines or other substances that are not allowed
- Do not follow the investigators instructions
- Do not take reasonable care of yourself

If you are harmed and the insurer pays for the necessary medical costs, usually you will be asked to accept that insurance payment as full settlement of the claim for medical costs. However, accepting this offer of insurance does not mean you give up the right to make a separate claim for other losses based on negligence, in a South African court.

It is important to follow the investigators instructions and to report straight away if you experience any adverse effect from the exercises.

Will there be COVID-19 protocols in place?

The schools COVID-19 policy will be strictly adhered to. In addition to this, we will do daily screening of any research assistants going onto school property. Equipment will be sterilised between participants and gloves and masks will be worn at all times. Social distancing during the intervention sessions will be strictly adhered to.

Who do I speak to (or contact) if I have questions about the study?

If at any time you have any questions or concerns about this study, please feel free to contact me or any of the individuals listed below. Please be assured that all enquiries will remain private and confidential.

Student investigator: **Mrs Kelly Mackenzie**

Physical address: Division of Physiological Sciences

	Department of Human Biology
	University of Cape Town
	Sports Science Institute of South Africa
	Boundary Road Newlands
	7700
Tel number:	083 388 9862
E-mail:	Kelly.mackenzie85@gmail.com
Principal Investigator:	**Dr. Janine Gray**
Physical address:	Division of Physiological Sciences
	Department of Human Biology
	University of Cape Town
	Sports Science Institute of South Africa
	Boundary Road Newlands
	7700
Tel number:	(021) 650 4557
Fax number:	(021) 650 1796
E-mail:	janineg@cricket.co.za
Co-supervisor:	**Professor Stephen Roche**
Physical address:	Division of Orthopaedics
	H49 OMB
	Groote Schuur Hospital
	Observatory 7925
Tel number:	(021) 4045108
Fax number:	(021) 4472709
E-mail:	stephen.roche@uct.ac.za

The UCT's Faculty of Health Sciences Human Research Ethics Committee can be contacted on 021 406 6338 (Prof. Marc Blockman, chair of the committee) in case you have any ethical concerns or questions about your rights or welfare as a participant on this research study.

Participant Assent Form

The Effects Of A Six Week Conditioning Program On Musculoskeletal Risk Factors, Shoulder Injury And Throwing Performance In Male Adolescent Water Polo Players In South Africa

I, the undersigned, have been fully informed about my inclusion in the study entitled: **"The Effects Of A Six Week Conditioning Program On Musculoskeletal Risk Factors, Shoulder Injury And Throwing Performance In Male Adolescent Water Polo Players In South Africa"** to be conducted by researchers from the Exercise Science and Sports Medicine Research Unit, Faculty of Health Sciences, University of Cape Town.

Please mark, with an "x", the parts of this study that you agree to participate in:

☐ I agree to participate in the shoulder musculoskeletal screening (pre and post intervention) and throwing performance testing (pre and post intervention) to be completed by a UCT research investigator. I understand that it will be necessary for me to perform a variety of tests as described above and I acknowledge that the testing will be done at "a designated location" and will require around 30-45 minutes of my time.

☐ I agree to complete an online survey once every week (that will be sent to my phone) for 6 weeks to monitor any injuries during the season.

☐ Should I be randomly placed in the intervention group, I agree to participate in two 10 minute exercise sessions per week, for the duration of six weeks.

☐ I agree to the shoulder musculoskeletal screening and injury monitoring data to be distributed within the UCT research team for part of the analysis as detailed above.

I have read and understood the Participation Information document and I have had the opportunity to ask questions regarding all that was stated. I know that I can ask any questions regarding my concerns throughout the duration of the study and I can stop my participation at any time without an explanation.

I agree to participate in this study.

______________________	_____________________	________________
Signature	**Full Name (Please Print)**	**Date**
______________________	_____________________	________________
Signature of Investigator	**Kelly Mackenzie**	**Date**

Appendix XI: Data collection form

DATA COLLECTION FORM

Date: ______________

SUBJECT CODE: ______________

Dominant Hand: **L / R**

1. ANTHROPOMETRIC DATA

Test	**1st**	**2nd**
Mass (kg)		
Standing Height (cm)		
Sitting Height (cm)		

2. SPECIAL TESTS

Test	**Dominant**	**Non-Dominant**
Hawkins/Kennedy		
Neer		
Jobe		

3. PASSIVE SHOULDER ROTATION RANGE OF MOTION

	Dominant		**Non-Dominant**	
Motion	1	2	1	2
GH Internal rotation				
GH External rotation				

4. UPWARD SCAPULA ROTATION (GH Abduction ROM)

	Dominant		**Non-Dominant**	
Motion	1	2	1	2
0°				
45°				
90°				
135°				

5. ISOMETRIC STRENGTH

Muscle Tested	Dominant		Non-Dominant	
	1	2	1	2
GH Internal rotation				
GH External rotation				
SA				
UT				
LT				

Where SA = Serratus Anterior; UT = Upper Trapezius and LT = Lower Trapezius

4. **LENGTH TESTS**

Muscle Tested	Dominant		Non-Dominant	
	1	2	1	2
PML				
PSC				

Where PML = Pectoralis Minor Length; PMI = Pectoralis Minor Index and PSC = Posterior Shoulder Complex Stiffness

7. CLOSED KINETIC CHAIN UPPER EXTREMITY STABILITY TEST

Trial #	Number of Touches
#1	
#2	
#3	
Total	

Type of Score	Score	Equation
Average Touch Score		Total of touch scores ÷ 3