An analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players

By

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I, Conor Beckett Gibb, do declare that this dissertation is representative of my own work in both conception and execution (except where acknowledgments indicate to the contrary)

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Dedication

I dedicate this dissertation to my parents, Alan and Danielle. I am eternally grateful for the sacrifices you have both made for me to reach this point. Your guidance and unwavering support have moulded me into the man I am today and without you I would never have reached such great heights. Words cannot express the gratitude I have for everything you do, and have done, for me. You walked so I could run. I love you both dearly. All the stars.

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Abstract

Background

Waterpolo is often compared to other sports, mainly swimming and overhead throwing sports. Swimming favours a posture of glenohumeral internal rotation and horizontal adduction. Overhead throwing sports can characteristically cause posterior shoulder immobility with a loss in glenohumeral internal rotation and horizontal adduction. Based on the fact that waterpolo players combine both swimming and overhead throwing whilst playing and training, it is the purpose of this study to investigate the sport-specific characteristics of the shoulder complexes of waterpolo players in an effort to determine how these unique characteristics may relate to the development of overuse injuries.

Aim

The aim of this study is to compare the dominant and non-dominant shoulder complexes of male water polo players in terms of posture, range of motion and sport-specific overuse injuries in order to develop an understanding of the combined effects of swimming and overhead throwing on the shoulders of water polo players.

Methods

The study used an observational based research design and consisted of 33 male waterpolo players currently competing in the Kwa-Zulu Natal mens 1st division waterpolo league. Participants underwent a shoulder digital posture examination as well as a shoulder-complex physical examination consisting of range of motion and orthopaedic testing which was then compared between the dominant and non-dominant shoulders. Participants were assessed for the presence of rotator cuff injury, glenoid labrum and LHBT injury, and anterior glenohumeral instability using the following physical tests: Empty can test, painful arc test, external rotation resistance, Hawkins-Kennedy test, Neer test, Yergassons test, Biceps Load test II, and the apprehension-relocation-surprise test. Glenohumeral range of motion was assessed using manual goniometry to measure passive internal and external rotation and horizontal adduction. Statistical analysis was performed using IBM SPSS version 27 statistical analysis software. Paired tests were used to compare outcomes from the

dominant and non-dominant shoulders of the participants. To compare the posture measurements, as well as injuries present between the dominant and non-dominant shoulders, McNemar's chi square tests were used. To compare the Range of motion measurements between the dominant and non-dominant shoulders, paired t-tests were used. A p value < 0.05 was considered statistically significant.

Results

Forward head posture with rounded shoulders was extremely common, with 73% of the participants in this study displaying a bilateral forward shoulder position ranging from moderate to severe, and 45% of participants displaying a bilateral forward head posture ranging from mild to severe. Glenohumeral internal and external rotation ROM measurements showed no difference between sides. There was a borderline significant difference (p=0.05) in the horizontal adduction measurements, with the non-dominant side showing greater values. The only injury test that yielded significant results was the empty can test for supraspinatus injury that had a higher prevalence for being positive on the dominant side.

Conclusion

The results of this study suggest that water polo players are prone to the development of a bilaterally equal forward head posture with rounded shoulders and are susceptible to similar mechanisms of bilateral overuse injury as swimmers. In addition, the dominant shoulders of these athletes are susceptible to damage caused by the repetitive, traumatic forces experienced by the posterior cuff musculature and posterior glenohumeral joint capsuloligamentous structures during the follow-through and deceleration phases of overhead throwing, resulting in an increased risk of supraspinatus-specific rotator cuff injury and a loss of glenohumeral horizontal adduction that potentially increases the risk of glenoid labrum and LHBT injury.

Key Terms

Water polo; overuse injury; forward head posture with rounded shoulders; posture; range of motion

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS & FIGURES

AADM	:	Acromiovertebral angle dominant side measurement
AADR	:	Acromiovertebral angle dominant side rating
AANM	:	Acromiovertebral angle non-dominant side measurement
AANR	:	Acromiovertebral angle non-dominant side rating
AC	:	Acromioclavicular
ARSTD	:	Apprehension-relocation-surprise test dominant arm
ARSTN	:	Apprehension-relocation- surprise test non-dominant arm
BLTD	:	Biceps load test II dominant arm
BLTN	:	Biceps load test II non-dominant arm
CADM	:	Craniovertebral angle dominant side measurement
CADR	:	Craniovertebral angle dominant side rating
CANM	:	Craniovertebral angle non-dominant side measurement
CANR	:	Craniovertebral angle non-dominant side rating
CC	:	Coracoclavicular
Dom	:	Hand dominance
DUT	:	Durban university of Technology
ECTD	:	Empty can test dominant arm
ECTN	:	Empty can test non-dominant arm
ER	:	External rotation
ERDP	:	External rotation dominant arm passive ROM
ERG	:	External rotation gain
ERNP	:	External rotation non-dominant arm passive ROM
ERRTD	:	External rotation resistance test dominant arm
ERRTN	:	External rotation resistance test non-dominant arm
FHA	:	Forward head angle
FHPRS	:	Forward head posture with rounded shoulders
FSA	:	Forward shoulder angle
GHJ	:	Glenohumeral joint
GIRD	:	Glenohumeral internal rotation deficit
GRF	:	Ground reaction force
HADP	:	Horizontal adduction dominant arm passive ROM

HANP	**:**	Horizontal adduction non-dominant arm passive ROM
HKTD	**:**	Hawkins-Kennedy test dominant arm
HKTN	**:**	Hawkins-Kennedy test non-dominant arm
IGHL	**:**	Inferior glenohumeral ligament
IR	**:**	Internal rotation
IRDP	**:**	Internal rotation dominant arm passive ROM
IREC	**:**	Institutional research ethics committee
IRNP	**:**	Internal rotation non-dominant arm passive ROM
KZN	**:**	Kwa-Zulu Natal
LHBT	**:**	Long head of the biceps tendon
LR	**:**	Likelihood ratio
n	**:**	Sample number
NTD	**:**	Neer's test dominant arm
NTN	**:**	Neer's test non-dominant arm
p	**:**	*p* value
PATD	**:**	Painful arc test dominant arm
PATN	**:**	Painful arc test non-dominant arm
PPS8	**:**	PosturePro Software Version 8
PSI	**:**	Posterior shoulder immobility
RCI	**:**	Rotator cuff injury
ROM	**:**	Range of motion
SAI	**:**	Subacromial impingement
SC	**:**	Sternoclavicular
SLAP	**:**	Superior labral lesions from anterior to posterior
SP	**:**	Spinous process
STJ	**:**	Scapulothoracic joint
TVP	**:**	Transverse process
YTD	**:**	Yergasson's test dominant arm
YTN	**:**	Yergasson's test non-dominant arm
%	**:**	Percent
<	**:**	Less than
>	**:**	Greater than
=	**:**	Equals

DEFINITIONS

Arm dominance:

The observed preference for using one arm over the other for a particular skilled motor task (Walker and Perreault 2015).

Capsuloligamentous structures:

Of or relating to the capsular surrounding of a synovial joint and its associated ligaments (Linklater, Hayter and Vu 2017).

Concentric contraction:

A type of muscle contraction in which the overall length of the muscle is shortened during the subsequent movement (Venes 2017: 552)

Eccentric contractions:

A type of muscle contraction in which the overall length of the muscle increases as it contracts against resistance (Venes 2017: 552).

Force-couple:

A biomechanical principal in which two or more muscles that act in different directions work in synchrony to control the motion of a joint (Donatelli 2016).

Overuse injuries:

An injury arising as a result of repetitive sub-maximal loading of a specific musculoskeletal unit, or a group of musculoskeletal units, resulting in pathological changes as a result of tissue fatigue or inflammation (Roos and Marshall 2014).

SLAP lesions:

A tear of the glenoid labrum in the anterior-posterior direction in the region where the biceps tendon anchors to the rim of the labrum (Venes 2017: 1385)

CHAPTER ONE
INTRODUCTION

1.1) Background

Originating in England, men's water polo was first introduced into the Olympic Games in 1900, making it the oldest team-sport in the Olympics (Galluccio et al. 2017; Miller et al. 2018). Water polo is a team-sport that involves two teams of seven players in a pool attempting to score by getting a ball into the opposition's goals. Each team consists of 6 outfield players and one goalkeeper, with a maximum of 6 substitutions on the bench and no limitations regarding how many times a player can be substituted. The main components of water polo are swimming and overhead throwing, mixed with shorter instances of blocking and tackling (Galluccio et al. 2017). Game play in water polo is extremely physically demanding, with players having to quickly transition between high and low intensity intervals while also having to hold their breath when swimming with the head underwater (Galluccio et al. 2017). In addition, certain phases of gameplay require unique biomechanics that allow the player to swim with their head above the water and the ball in front of them (Galluccio et al. 2017). Games typically last approximately one hour which requires a great deal of cardiovascular fitness (Webster, Morris and Galna 2009). As a result, many elite players train three to four times a week, during which they may swim between 2km and 5km per session (Webster, Morris and Galna 2009).

Shoulder overuse pathologies have been identified as the leading cause of injury amongst water polo players of all levels, with some studies finding an incidence as high as 80% amongst high-level athletes (Franic, Ivkovic and Rudic 2007; Webster, Morris and Galna 2009; Miller et al. 2018). Despite these high levels of injury being identified as early as 1999 (Colville and Markman 1999), a study by Mountjoy and Junge (2011) found that, between 2004 and 2008, the overall incidence of injury in water polo remained the same. This shows the lack of effect that the development and implementation of current water polo injury identification and prevention programmes have had, while also highlighting the necessity for further research into the mechanisms of development of these injuries and how this may be prevented.

1.2) Aims and Objectives

1.2.1) Research Problem

The mechanism of development of shoulder overuse injuries in water polo is often likened to that of swimming (Borsa, Laudner and Sauers 2008; Ferragut et al. 2011; Galluccio et al. 2017). However, because the dominant shoulders of water polo players undergo both the forces of swimming and overhead throwing, there is a unique mechanism of injury occurring in the shoulders of these athletes that has yet to be fully explored (Galluccio et al. 2017).

1.2.2) Aim of The Study

The aim of this study is to compare the dominant and non-dominant shoulder complexes of male water polo players in terms of posture, range of motion and current overuse injuries in order to develop an understanding of the combined effects of swimming and overhead throwing on the shoulders of water polo players.

1.2.3) Study Objectives

1. To perform a digital posture examination to measure the acromiovertebral angle and the craniovertebral angle of male water polo players.
2. To bilaterally measure glenohumeral internal rotation, external rotation and horizontal adduction range of motion in male water polo players using goniometry.
3. To identify the presence of any current sport-specific shoulder overuse injuries in male water polo players using a sport-specific shoulder orthopaedic examination.
4. To compare the posture measurements, range of motion and injury assessment in the dominant and non-dominant shoulders of male water polo players.

1.3) Hypotheses

1.3.1) Null Hypothesis

The null hypothesis (H_0) states that there will be no statistically significant (p<0.05) difference in the sport-specific measurements for posture, range of motion and overuse injuries between the dominant and non-dominant shoulders of the participants.

1.3.2) Alternate Hypothesis

The alternate hypothesis (H_a) states that there will be a statistically significant difference (p<0.05) in the sport-specific measurements for posture, range of motion and overuse injuries between the dominant and non-dominant shoulders of the participants.

1.4) Study Rationale

There is a contradiction in the literature with regards to the sport-specific adaptations in the shoulders of water polo players, occurring as a result of the combined effects of swimming and overhead throwing. The bilateral differences in the shoulders of these athletes presents the opportunity to identify the effect of the overhead throwing forces combined with the micro-trauma of swimming by comparing the sport-specific changes in the dominant and non-dominant shoulders of these players. By identifying these sport-specific changes we can better understand the mechanism of development of these shoulder overuse injuries which will allow us to implement a more effective preventative programme.

1.5) Delimitations of The Study

According to several authors, physical tests alone are not sufficient for the diagnosis of some of the injuries included in this study (Michener *et al.* 2009; Hegedus *et al.* 2012). However, as a result of financial and time constraints, it was decided to use physical tests as opposed to imaging provided that the tests used had acceptable levels of validity, sensitivity and specificity.

This study only looked at asymptomatic water polo players in order to ensure that they would be able to perform all the necessary physical tests. As a result, the conclusions of this study may not be directly applicable to symptomatic players.

The main range of motion adaptations relevant to these athletes that are described in the literature exclusively involve glenohumeral internal rotation, external rotation and horizontal adduction (Borsa, Laudner and Sauers 2008; Lynch *et al.* 2010; Turgut *et al.* 2018). As a result, it was decided that only these motions would be assessed.

Water polo players have been found to have a characteristic posture of a forward head with rounded shoulders (Aginsky, Tracey and Neophytou 2016). As a result, it was decided that the posture assessment would assess exclusively for these postural changes.

1.6) Flow of Dissertation

Chapter One has provided an introduction to water polo and the problem of shoulder overuse injuries amongst water polo players, as well as going over the aims, objectives and rationale of the study.

Chapter Two will provide a review of the current literature relevant to the study and will cover the relevant anatomy of the shoulder girdle, the biomechanics of water polo and the adaptations that occur as a result of these biomechanics, and the mechanisms of injury development in the shoulders of water polo players.

Chapter Three will provide an in-depth description of the methodology of the study. The study design, procedure and the instruments used will be discussed in detail.

Chapter Four will present the results of the study.

Chapter Five provides a discussion of the results in terms of the current literature.

Chapter Six provides a conclusion to the study as well as mentioning any limitations to this study and any recommendations for future studies.

CHAPTER TWO
LITERATURE REVIEW

2.1) Introduction

This chapter will attempt to explore all of the relevant literature surrounding shoulder overuse injuries in water polo. The first section will discuss the anatomy relevant to this study, namely the bones, joints, ligaments, muscles and tendons, and the normal functioning of the shoulder girdle. The next section will discuss the biomechanics of water polo, focusing on the biomechanics of swimming and throwing and then discussing the sport-specific adaptations that occur in the shoulders of water polo players. The final section in this chapter will discuss the common shoulder overuse injuries found in water polo players and the proposed mechanisms of development of these injuries.

2.2) Relevant Anatomy of The Shoulder Girdle

The shoulder girdle is a bony ring formed by the clavicle and the scapula, which articulates with the proximal end of the humerus to form the most mobile joint in the body - the glenohumeral joint (Miniato and Caire 2019). The glenohumeral joint achieves its wide range of mobility at the expense of stability and, as a result, the structures of the shoulder girdle are extremely prone to injury (Moore, Dalley and Agur 2013; Miniato and Caire 2019). In addition to the glenohumeral joint, the shoulder girdle is comprised of the sternoclavicular joint, the acromioclavicular joint and the scapulothoracic joint (Moore, Dalley and Agur 2013).

The following section will review the anatomy of the structures of the shoulder girdle that are relevant to shoulder overuse injuries in water polo players. These include the bones, joints, ligaments, and muscles and tendons of the shoulder girdle. The bones which are to be discussed include the clavicle, the scapula and the humerus. The joints include the sternoclavicular and acromioclavicular joints, the scapulo-thoracic joint and the glenohumeral joint, along with the relevant ligaments of these joints. The muscles and tendons discussed include the rotator cuff muscles and the long head of the biceps and glenoid labrum.

2.2.1) Bones of the Shoulder Girdle

2.2.1.1) The Clavicle

The clavicle is the elongated bone that forms the front of the shoulder girdle (Moore, Dalley and Agur 2013). The clavicle forms a rigid, yet mobile, crank that functions as the only bony connection between the axial skeleton and the upper limb and allows free movement of the scapula and glenohumeral joint by holding these structures away from the thorax as a result of its double curve (Moore, Dalley and Agur 2013; Saccomanno, De Ieso and Milano 2014). At its proximal end the clavicle articulates with the sternum at the sternoclavicular joint and at its distal end it articulates with the acromion of the scapula at the acromioclavicular joint (Moore, Dalley and Agur 2013).

2.2.1.2) The Scapula

The scapula is a thin, flat, triangular bone located on the posterior aspect of the thorax; it contains multiple important osseous features and, as the main structure of the complex scapulothoracic joint, it plays a substantial role in overall shoulder function (Frank *et al.* 2013; Moore, Dalley and Agur 2013). The scapula has a medial, a superior and a lateral edge (Frank et al. 2013). According to Frank *et al.* (2013) and Moore, Dalley and Agur (2013), the most important osseous features of the scapula are the spine, the acromion, the coracoid process and the glenoid cavity.

The spine of the scapula is a bony ridge on the posterior aspect of the scapula that runs from the medial edge to the supero-lateral angle and divides the posterior surface into a large infraspinous fossa and a smaller supraspinous fossa (Moore, Dalley and Agur 2013). The acromion articulates with the distal clavicle at the acromioclavicular joint and, therefore, plays an important role in augmenting glenohumeral joint motion (Frank *et al.* 2013). The acromion constitutes a large portion of the coracoacromial arch that functions to prevent excessive superior translation of the humeral head (Le Reun *et al.* 2016). The coracoid process is a beak-like structure that projects antero-laterally from the superior border of the scapula, medial to the glenoid, that serves as an important site for the attachment of ligaments and muscles, as well as contributing to the coracoacromial arch (Frank *et al.* 2013; Le Reun *et al.* 2016). The supero-lateral aspect of the scapula extends laterally to form a shallow, concave, oval cavity, called the glenoid cavity, that articulates with the large humeral head to form the glenohumeral joint (Moore, Dalley and Agur 2013). Because the glenoid cavity is small and shallow compared to the large, round head of the humerus, it is only capable of accepting 1/3 to 1/4 of the humeral head and is, resultantly, functionally deepened by a fibrocartilagenous ring, called the glenoid labrum, that covers the rim of the glenoid (Frank *et al.* 2013; Moore, Dalley and Agur 2013).

2.2.1.3) The humerus

The humerus is the largest bone in the upper limb and articulates with the glenoid cavity of the scapula at the glenohumeral joint (Moore, Dalley and Agur 2013). The proximal end of the humerus has several important osseous features, the most important of which, with regards to this study, are the head, the greater and lesser tubercles, and the inter tubercular groove. The head of the humerus is large and round when compared to the shallow glenoid cavity; this allows the glenohumeral joint to have a wide range of motion in nearly all directions but requires greater effort from surrounding structures in order to maintain stability (Miniato and Caire 2019). The anterior and lateral aspects of the humeral head are dominated by bony ridges called the greater and lesser tubercles (Moore, Dalley and Agur 2013). The lesser tubercle projects anteriorly from the humeral head and the greater tubercle projects laterally; both tubercles serve as important attachment sites for the ligaments and tendons of the glenohumeral joint (Moore, Dalley and Agur 2013; Miniato and Caire 2019). The inter-tubercular groove runs between the greater and lesser tubercles and serves to guide the tendon of the long head of the biceps as it travels down the humerus, as well as serving as an attachment site for several important muscles (Moore, Dalley and Agur 2013; Miniato and Caire 2019).

2.2.2) Joints of The Shoulder Girdle

2.2.2.1) The Sternoclavicular and Acromioclavicular Joints

The sternoclavicular (SC) joint is a synovial joint located on the superior aspect of the anterior boney thorax and is the articulation between the sternal end of the clavicle and the superior aspect of the lateral surface of the manubrium and the first costal cartilage (Moore, Dalley and Agur 2013). Though considered a saddle-type joint, the sternoclavicular joint functions as a ball-and-socket joint which allows it to move in three degrees of freedom – protraction/retraction, elevation/depression and axial rotation (Moore, Dalley and Agur 2013). The SC joint is the only true joint between the upper limb and the axial skeleton and works as a pivot between these systems to increase the versatility of upper limb movement (Moore, Dalley and Agur 2013).

The acromioclavicular joint (AC joint) is a plane-type of synovial joint formed by the articulation between the distal end of the clavicle and the acromion of the scapula and, therefore, forms the distal articulation of the clavicular crank that suspends the scapula and upper limb away from the thorax (Moore, Dalley and Agur 2013; Saccomanno, De Ieso and Milano 2014). As a result of its thin joint capsule, static and dynamic stabilisers maintain stability of the AC joint. Dynamic stability is provided by the deltoids anteriorly and the trapezius posteriorly while the primary static stability is provided by the acromioclavicular, coracoclavicular and coraco-acromial ligament complexes (Ha, Petscavage-Thomas and Tagoylo 2014; Saccomanno, De Ieso and Milano 2014).

2.2.2.1.1) Ligaments of the SC and AC Joints

The joint capsule of the SC joint is reinforced anteriorly and posteriorly by the anterior and posterior SC ligaments, respectively, and superiorly by the single inter-clavicular ligament; these ligaments greatly increase the stability, and therefore strength, of the sternoclavicular joint (Moore, Dalley and Agur 2013).

The acromioclavicular ligaments are thickenings of the joint capsule of the AC joint that serve to reinforce the thin capsule and are made up of the anterior, posterior, inferior and superior AC ligaments (Ha, Petscavage-Thomas and Tagoylo 2014). The combined AC ligament complex is capable of providing three times more stability in the A-P direction than in the S-I direction (Saccomanno, De Ieso and Milano 2014). Therefore, the AC ligaments are responsible for the horizontal stability of the AC joint by functioning as the primary restraint to posterior displacement and posterior axial rotation of the clavicle (Ha, Petscavage-Thomas and Tagoylo 2014; Saccomanno, De Ieso and Milano 2014).

The coraco-clavicular (CC) ligaments are a pair of distinct ligaments that span from the coracoid process inferiorly to the inferior surface of the clavicle superiorly (Moore, Dalley and Agur 2013). Consisting of the conoid and trapezoid ligaments, the CC ligament complex functions primarily to maintain vertical stability of the AC joint by anchoring the clavicle inferiorly to the coracoid process (Ha, Petscavage-Thomas and Tagoylo 2014; Saccomanno, De Ieso and Milano 2014).

2.2.2.1.2) Movement of the SC and AC Joints

Movements of the SC joint are functionally linked to movements of the shoulder and pectoral girdle (Moore, Dalley and Agur 2013). The predominant motion of the SC joint is anterior-posterior translation of the clavicle (protraction/retraction) of up to 35^{o} in the A-P direction, which occurs during horizontal adduction and abduction (Moore, Dalley and Agur 2013). Elevation of the clavicle of up to 60^{o} occurs during full elevation of the shoulder (Moore, Dalley and Agur 2013). Flexion and extension of the shoulder can also cause elevation, depression and longitudinal rotation of the clavicle (Moore, Dalley and Agur 2013).

With regards to movement of the AC joint; the acromion of the scapula articulates with the distal end of the clavicle and, therefore, motion of the AC joint is described as movement of the scapula relative to the clavicle (Moore, Dalley and Agur 2013). Motion at the AC joint is produced by muscles that attach to the scapula causing movement of the acromion on the clavicle (Moore, Dalley and Agur 2013).
According to Teece *et al.* (2008), the AC joint has 6 degrees of freedom:

- Upward and downward rotation about an axis angled anteriorly and slightly medially, perpendicular to the plane of the scapula

- Internal and external rotation about a vertical axis
- Anterior and posterior tilting (also referred to as tipping) about a horizontal axis

Teece *et al.* (2008) added that a healthy AC joint can allow up to 6mm of anterior, posterior or superior translation and can rotate between 5-8^{o} during scapulo-thoracic motion and between 40-45^{o} during shoulder abduction and elevation.

2.2.2.2) The Scapulothoracic Joint

The scapulothoracic joint is a physiological joint located on the postero-lateral thorax, formed by the movement of the scapula along the posterior surface of the thorax, and is the only articulation in the shoulder girdle that is not considered a true joint (Frank *et al.* 2013). Unlike the acromioclavicular, sternoclavicular and glenohumeral joints, the scapulothoracic joint does not contain a joint capsule, synovium or any articular cartilage; rather, it consists of a series of muscular planes that allow the scapula to slide freely while being suspended away from the posterior thorax (Frank *et al.* 2013; Saccomanno, De Ieso and Milano 2014).

2.2.2.2.1) Movement of the Scapulothoracic Joint

As a result of its lack of a bony articulation and its purely muscular support, movement of the scapulothoracic joint is defined by a sliding of the scapula along the posterior thorax, with the glenoid serving as a reference point when describing this motion; therefore, the scapulothoracic joint is capable of considerable movement during motion of the upper limb and permits the following movements of the scapula: protraction/retraction, elevation/depression, anterior/posterior tilting, and upward/downward rotation (Paine and Voight 2013). Though this motion of the scapula occurs at the scapulothoracic joint, it is actually brought about by the action of the periscapular muscles causing motion at the sternoclavicular and acromioclavicular joints (Teece *et al.* 2008).

2.2.2.3) The Glenohumeral Joint

The glenohumeral joint (GHJ) is the main joint of the shoulder girdle and is formed by the articulation between the shallow glenoid cavity of the scapula and the large, round humeral head (Moore, Dalley and Agur 2013; Chang and Varacallo 2019). The GHJ is a multi-axial ball-and-socket type synovial joint that permits a wide range of motion (Kishner, Munshi and Black 2017). This wide range of motion makes the GHJ the most mobile joint in the body but also decreases the stability of the joint and is one of the reasons that the GHJ is the most commonly dislocated joint in the body (Chang and Varacallo 2019).

Being a synovial joint, the entire joint is surrounded by a fibrous joint capsule; the articular surfaces are lined by articular cartilage and a synovial membrane lines the internal surface of the capsule, the labrum, and the humeral head up to the articular margins (Moore, Dalley and Agur 2013; Chang and Varacallo 2019). The inferior part of the capsule is the only part not supported by the rotator cuff and is, therefore, the weakest; however, while the inferior part of the capsule is lax and folded when the arm is in adduction, it begins to tauten when the arm is elevated, providing more support (Moore, Dalley and Agur 2013). The mobility of the GHJ occurs as a result of a combination of this relatively loose joint capsule and the large size of the humeral head relative to the shallow glenoid cavity (Chang and Varacallo 2019). The rim of the glenoid cavity is lined by a fibrocartilagenous ring called the glenoid labrum that is continuous with the long head of the biceps tendon at its superior aspect and functions to structurally deepen the shallow glenoid cavity in order to increase stability of the joint during motion (Kishner, Munshi and Black 2017; Chang and Varacallo 2019).

Present around the glenohumeral joint are multiple fluid-filled sac-like cavities called bursae, the most important of which is the subacromial bursa (Chang and Varacallo 2019). The subacromial bursa, also known as the sub-deltoid bursa, is positioned superior to the glenohumeral joint and is located between the acromion, the coraco-acromial ligament and the deltoid superiorly and the supraspinatus tendon and glenohumeral joint capsule inferiorly (Moore, Dalley and Agur 2013). The subacromial bursa functions to facilitate movement of the supraspinatus tendon under the coraco-acromial arch and to facilitate movement of the deltoid tendon over the glenohumeral joint and the greater tubercle of the humerus in order to allow increased range of motion (Moore, Dalley and Agur 2013; Chang and Varacallo 2019). The coracoacromial arch is an extrinsic, osseo-ligamentous, protective structure superior to the glenohumeral joint formed by the bony anatomy of the scapula and the coracoacromial ligament; it is comprised of the coracoacromial ligament, the acromion and the coracoid process of the scapula (Moore, Dalley and Agur 2013). However, despite the friction-mitigating effect of the bursa, the coracoacromial ligament has long been implicated in contributing to pain caused by movement of the rotator cuff tendons against the arch (Rothenberg *et al.* 2017).

2.2.2.3.1) Ligaments of The Glenohumeral Joint

The capsulolabral complex contains important thickened bands located on the internal aspect of the anterior part of the joint capsule that constitute the superior, middle and inferior glenohumeral ligaments, with the inferior glenohumeral ligament (IGHL) consisting of anterior and posterior bands (Armfield *et al.* 2003; Chang and Varacallo 2019). The glenohumeral ligaments originate from the labrum near the supraglenoid tubercle and run inferiorly and laterally to insert onto the anatomical neck of the humerus after blending with the fibrous layer of the joint capsule and function as the primary anterior stabilizers of the joint, preventing anterior translation of the humeral head (Moore, Dalley and Agur 2013; Chang and Varacallo 2019). The GHJ is also supported by the coracohumeral ligament that is located on the anterosuperior aspect of the joint and originates proximally from the base of the coracoid process and attaches distally to the anterior aspect of the greater tubercle of the humerus (Chang and Varacallo 2019).

The coracoacromial ligament is a short and rigid ligament that extends infero-medially from its origin on the inferior aspect of the antero-lateral surface of the acromion to its insertion on the lateral border of the coracoid process (Rothenberg *et al.* 2017). The combination of the coracoacromial ligament, the acromion and the coracoid process forms a strong, rigid, static restraint that resists superior humeral head displacement (Moore, Dalley and Agur 2013; Rothenberg *et al.* 2017).

2.2.2.3.2) Movement of The Glenohumeral Joint

The glenohumeral joint has the most freedom of movement out of all the joints in the body but full glenohumeral range of motion is only possible through a complex inter-connection of biomechanical chains (Moore, Dalley and Agur 2013). According to Moore, Dalley and Agur (2013) and Chang and Varacallo (2019), the glenohumeral joint permits movement about three axes:

1) Flexion (180^{o}) and extension (45-60^{o}) about a horizontal axis in the coronal plane going through the center of rotation of the joint
2) Abduction (90^{o} true GHJ motion) or adduction (90^{o}) about a horizontal axis in the sagittal plane going through the center of rotation of the joint
3) Internal (70-90^{o}) and external (90^{o}) rotation about a vertical axis through the center of rotation of the joint

In addition to these motions, the GHJ is capable of producing full circumduction in both directions, though this is an orderly sequence of flexion-abduction-extension-adduction (or the reverse) and is augmented by movement at the AC and SC joints (Moore, Dalley and Agur 2013).

2.2.3) Relevant Muscles of The Shoulder Girdle

The muscles of the shoulder can be broadly broken down into two groups based on their attachment sites – intrinsic muscles and extrinsic muscles. The extrinsic muscles of the shoulder, or axio-appendicular muscles, originate from the torso and attach to the bones of the shoulder girdle (clavicle, scapula or humerus); the intrinsic muscles of the shoulder, or scapulohumeral muscles, originate from the scapula and insert onto the humerus (Moore, Dalley and Agur 2013).

The extrinsic shoulder muscles consist of the anterior axio-appendicular muscles and the superficial and deep groups of posterior axio-appendicular muscles. The anterior axio-appendicular muscles consist of the pectoralis major and minor, the subclavius and the serratus anterior (Moore, Dalley and Agur 2013). The superficial posterior axio-appendicular muscles consist of the trapezius and latissimus dorsi, and the deep posterior axio-appendicular muscles consist of the levator scapulae and rhomboid major and minor muscles (Moore, Dalley and Agur 2013). The scapulohumeral muscles consist of the deltoid, teres major, and the four rotator cuff muscles – supraspinatus, infraspinatus, teres minor and subscapularis (Moore, Dalley and Agur 2013). Of additional note is a muscle of the arm that plays a significant role in the functioning of the shoulder girdle – the biceps brachii (Moore, Dalley and Agur 2013).

In this section we will discuss, in detail, the muscles of the shoulder that are relevant to this study – the supraspinatus, infraspinatus, teres minor, subscapularis, and biceps brachii. The origins, insertions, actions and innervation of the remainder of the aforementioned shoulder muscles, which are not discussed in depth in this section, can be found in Table 2.1.

2.2.3.1) The Rotator Cuff: Supraspinatus, Infraspinatus, Teres Minor and Subscapularis

The rotator cuff is a group of four muscles, and their tendons, that function to stabilize the humeral head in the glenoid cavity and assist in movement of the glenohumeral joint (Aboelmagd, Rees and Gwilym 2018). Each muscle of the rotator cuff originates on the scapula and attaches, via a tendon, to one of the tubercles of the humerus, forming a strong cuff around the glenohumeral joint (Cooper and Ali 2013; Aboelmagd, Rees and Gwilym 2018). Before inserting into the humerus, the tendons of the rotator cuff blend with the fibrous layer of the joint capsule of the glenohumeral joint, further reinforcing it (Moore, Dalley and Agur 2013).

All of the rotator cuff muscles, except supraspinatus, act individually as rotators of the humerus, though their most important role is functioning together to stabilize the humeral head (Moore, Dalley and Agur 2013). During abduction of the shoulder, the rotator cuff muscles work together to compress the head of the humerus into the glenoid cavity in a process known as concavity compression; this force adds stability to the glenohumeral joint (Cooper and Ali 2013). During abduction, the muscles of the rotator cuff must function in perfect balance in order to control the movement of the humerus relative to the scapula. Therefore, during abduction, the anterior cuff muscle, subscapularis, works to prevent anterior humeral head translation while the posterior cuff muscles, the infraspinatus and teres minor, work to prevent posterior translation of the humeral head (Cooper and Ali 2013; Vollans and Ali 2016). The middle/superior cuff muscle, supraspinatus, plays an even more important role in abduction of the glenohumeral joint. The deltoid muscle is the primary abductor of the glenohumeral joint but, because of its resting position, it is unable to initiate abduction of the joint (Moore, Dalley and Agur 2013). Therefore, the supraspinatus muscle is responsible for initiating the first 15° of glenohumeral abduction, after which the deltoid becomes fully effective as an abductor and takes over as the primary muscle in the movement (Moore, Dalley and Agur 2013). As a result of this continued activity, the tonic contraction of the rotator cuff keeps the large head of the humerus in the shallow glenoid during all movements of the upper limb (Moore, Dalley and Agur 2013).

2.2.3.1.1) Supraspinatus

The supraspinatus muscle resides in the supraspinous fossa on the dorsal aspect of the scapula, superior to the scapular spine (Moore, Dalley and Agur 2013; Jeno and Schindler 2019). Laterally, the tendon of the supraspinatus blends with the fibers of the glenohumeral joint capsule before inserting into the superior facet of the greater tubercle of the humerus (Jeno and Schindler 2019). Before inserting on the humerus, the supraspinatus muscle must first pass through the narrow canal formed by the osseo-ligamentous coracoacromial arch above and the rim of the glenoid below (Moore, Dalley and Agur 2013). The passage of the supraspinatus tendon through such a narrow canal makes it extremely susceptible to mechanical impingement during over-head movements of the arm, as the tendon has to curve superiorly around the coracoacromial arch to follow the humerus, contributing to the supraspinatus tendon being the most commonly injured tendon in the rotator cuff (Morag *et al.* 2011; Le Reun *et al.* 2016).

Acting independent of the other rotator cuff muscles, the supraspinatus is responsible for initiating the first 15° of glenohumeral abduction (Moore, Dalley and Agur 2013). Once the deltoid takes over as the primary abductor after 15° of abduction, the supraspinatus continues to assist with the movement but plays more of a supporting role, stabilizing the humeral head so that the deltoid has a stable attachment (Moore, Dalley and Agur 2013; Jeno and Schindler 2019). Functioning with the rest of the rotator cuff, the supraspinatus stabilizes the head of the humerus in the glenoid cavity through all movements of the glenohumeral joint (Moore, Dalley and Agur 2013).

Table 2.1: Relevant Muscles of The Shoulder Girdle

Muscle	Origin	Insertion	Action	Innervation
Teres Major	Dorsal surface of the inferior angle of the scapula	Crest of the lesser tubercle of the humerus	-Assists in adduction, medial rotation and extension of the arm from the flexed position -Strongly activated when arm adducted across the back	Lower subscapular nerve
Deltoid	Lateral third of the clavicle, acromion and spine of the scapula	Deltoid tuberosity of the humerus	-Anterior fibers flex arm at GHJ -Middle fibers abduct arm at GHJ -Posterior fibers extend arm at GHJ -Combined all fibers assist supraspinatus in abduction of the arm at GHJ	Axillary nerve
Trapezius	Medial third of superior nuchal line, external occipital protuberance, ligamentum nuchae and SPs of C7-T12 vertebrae	Lateral third of the clavicle, medial acromion and scapular spine	-Upper fibers rotate scapula upward and draw clavicles backwards -Middle fibers strongly adduct the scapula -Lower fibers stabilize scapula during rotation	Spinal accessory nerve
Rhomboid Major	SPs of vertebrae T2-T5	Medial border of scapula inferior to spine of scapula	-Adduct and medially rotate the scapula	Dorsal scapular nerve
Rhomboid Minor	SPs of C7 and T1	Medial border of scapula at root of spine of scapula	-Adduct and medially rotate the scapula	Dorsal scapular nerve
Serratus Anterior	Antero-lateral surface of ribs 1-9	Anterior surface of vertebral border of the scapula	-Upward rotation, abduction and elevation of the scapula -Secures medial border of scapula against thoracic wall	Long thoracic nerve
Levator Scapula	TVPs of C1-4 vertebrae	Medial border of scapula from superior angle to root of spine of scapula	-Downward rotation and elevation of the scapula -Assists in movement of neck when scapula fixed in place	Dorsal scapular nerve
Pectoralis Major	Ant. surface of medial half of clavicle, ant. surface of sternum, ant. aspect of costal cartilages 1-6	Lateral lip of intertubercular groove of humerus	-Adduction and internal rotation of humerus -Draws scapula anteriorly and inferiorly -Clavicular head flexes humerus and sternocostal head extends it	Lateral and medial pectoral nerves
Pectoralis Minor	Anterior surface of ribs 3-5	Medial aspect of tip of coracoid process	-Stabilizes the scapula by pulling it inferiorly and anteriorly against the chest wall	Medial pectoral nerve

(Adapted from Frank *et al.* (2013); Moore, Dalley and Agur (2013) and Simons, Travell and Simons (1999))

2.2.3.1.2) Infraspinatus

The infraspinatus muscle covers the vast majority of the dorsal surface of the scapula and is partly covered by the deltoid and trapezius muscles; originating below the scapular spine in the infraspinous fossa and extending laterally to insert into the middle facet of the greater tubercle of the humerus (Moore, Dalley and Agur 2013). Functioning independently of the other rotator cuff muscles, the infraspinatus powerfully laterally rotates the humerus at the glenohumeral joint; functioning with the rotator cuff, the infraspinatus assists in stabilization of the humeral head during all movements of the upper limb (Moore, Dalley and Agur 2013).

2.2.3.1.3) Teres Minor

The teres minor is a narrow, elongated muscle that lies in close proximity to infraspinatus (Moore, Dalley and Agur 2013). Medially, the teres minor attaches to the superior 2/3 of the lateral border of the scapula; laterally, it inserts into the inferior facet of the greater tubercle of the humerus (Moore, Dalley and Agur 2013). Teres minor assists infraspinatus with lateral rotation of the humerus and works with the rest of the rotator cuff to stabilize the humeral head (Moore, Dalley and Agur 2013).

2.2.3.1.4) Subscapularis

The large, triangular subscapularis muscle is the most powerful of all the rotator cuff muscles, attaching medially to the costal surface of the scapula and extending laterally, crossing anterior to the glenohumeral joint, to form a flat tendon that attaches to the lesser tubercle on the anterior aspect of the humerus (Morag *et al.* 2011; Moore, Dalley and Agur 2013). The passage of the subscapularis tendon from the scapula to the anterior aspect of the humerus makes the muscle a powerful internal rotator of the humerus at the glenohumeral joint, as well as allowing it to assist with adduction when the arm is in certain positions (Morag *et al.* 2011; Moore, Dalley and Agur 2013). Functioning with the rest of the rotator cuff, the subscapularis stabilizes the head of the humerus during all movements of the upper limb (Moore, Dalley and Agur 2013).

2.2.3.2) The long Head of Biceps Brachii and The Glenoid Labrum

The biceps brachii is a thick muscle that has two proximal heads that originate, through tendinous insertions, from processes on the scapula and converge in the middle of the anterior humerus to extend inferiorly and attach to the forearm (Moore, Dalley and Agur 2013; Zappia *et al.* 2013). The long head of the biceps is a complicated structure, consisting of both intra- and extra-articular portions as well as several supporting mechanisms (Longo *et al.* 2011; Zappia *et al.* 2013). The tendon of the long head of the biceps originates within the glenohumeral joint as a flat tendon attaching to the supraglenoid tubercle of the scapula and the superior part of the glenoid labrum (Longo *et al.* 2011; Moore, Dalley and Agur 2013). This intra-articular portion of the long head of the biceps tendon travels laterally to exit the glenohumeral joint and then enters the inter-tubercular groove, where it travels inferiorly down the anterior aspect of the humerus to join with the short head just below the middle of the humeral shaft (Longo *et al.* 2011; Moore, Dalley and Agur 2013). The tendon of the long head is supported by various structures along its course; the most important supporting structure is the glenoid labrum (Longo *et al.* 2011; Moore, Dalley and Agur 2013; Zappia *et al.* 2013).

The glenoid labrum is a circumferential ring of fibrocartilage located on the rim of the glenoid cavity that serves to stabilize the glenohumeral joint (Smith and Funk 2010). The labrum contributes in many ways to the stability of the glenohumeral joint but serves two main functions. The primary role of the labrum is to functionally increase the depth of the shallow glenoid cavity so that it may accept more of the large humeral head (Smith and Funk 2010). Additionally, the labrum provides a strong site of attachment for other supporting structures, such as the long head of the biceps tendon and the glenohumeral ligaments (Smith and Funk 2010; Clavert 2015).

Despite its ability to cause movement at the glenohumeral, radio-ulnar and elbow joints, the biceps primarily plays a supporting role at the glenohumeral joint, with the short head resisting inferior dislocation of the shoulder and the long head assisting in stabilization of the superior aspect of the joint and weakly assisting in flexion (Moore, Dalley and Agur 2013). The biceps brachii acts primarily at the elbow and radio-ulnar joints, causing flexion of the extended elbow and powerful supination of the flexed elbow (Moore, Dalley and Agur 2013).

2.2.4) Normal Biomechanics and Functioning of the Shoulder Girdle

The shoulder complex as a whole represents a fine balance between mobility and stability, with the large difference in size between the articulating surfaces and the loose capsule of the glenohumeral joint allowing a great deal of mobility that needs to be kept in check by the limiting effect of the dynamic and static stabilizers (Veeger and van der Helm 2007; Chang and Varacallo 2019). This compromise between mobility and stability is the ultimate goal of the biomechanical systems that control the shoulder complex; therefore, the purpose of all of the joints in the shoulder, and their surrounding musculo-ligamentous supports, is to effectively position the glenoid relative to the humeral head and provide stability to this system throughout all movements of the upper extremity (Armfield *et al.* 2003; Lugo, Kung and Ma 2008).

2.2.4.1) Stability of The Shoulder

The shoulder complex is generally considered a closed chain system in which the thorax, scapula and clavicle form a closed chain that positions the humeral head (Veeger and van der Helm 2007). The minimal bony covering and limited contact areas of the glenohumeral joint allow excessive translational and rotational abilities of the humeral head; this results in a large amount of mobility at the expense of stability (Armfield *et al.* 2003; Veeger and van der Helm 2007). Therefore, in order for effective stabilization to be achieved, static and dynamic stabilizers must constrain excessive joint translations, redirecting the force towards the articular surfaces and thereby increasing the compression of the humeral head into the glenoid (Veeger and van der Helm 2007; Lugo, Kung and Ma 2008).

2.2.4.1.1) Static Stability

The mismatch between the articulating surfaces of the humeral head and the glenoid cavity means that a maximum of only 30% of the articular cartilage of the humeral head is in contact with the articular cartilage of the glenoid at any time, making the glenohumeral joint inherently unstable (Lugo, Kung and Ma 2008). The humeral head and the glenoid must stabilize the joint by maintaining a relatively constant volume in the joint capsule and maintaining tension in the supporting ligaments; this prevents excessive translation of the humeral head by creating a negative intra-articular pressure (Lugo, Kung and Ma 2008). In addition to this, the glenoid is functionally deepened by the fibrocartilagenous labrum (Lugo, Kung and Ma 2008; Bain *et al.* 2013). As a result, the humeral head is compressed into the deepened glenoid cavity by negative intra-articular pressure and the force of concavity compression generated by the stabilizing muscles (Lugo, Kung and Ma 2008). The tendon of the long head of the biceps also plays an important role in static stabilization of the glenohumeral joint by maintaining proper tension in the glenohumeral ligaments through depression of the humeral head (Lugo, Kung and Ma 2008; Moore, Dalley and Agur 2013).

The glenohumeral ligament complex, located on the anterior aspect of the glenohumeral joint capsule, functions as a check-rein during glenohumeral joint motion, with each ligament providing stability to the joint throughout various different positions during joint motion (Lugo, Kung and Ma 2008). The inferior glenohumeral ligament is thought to be the most important restraint to antero-inferior dislocation of the humeral head and plays a major role as the primary anterior stabilizer of the humeral head during external rotation in the abducted shoulder, such as during the wind-up and cocking phases of throwing (Armfield *et al.* 2003; Veeger and van der Helm 2007). Additionally, the anterior and posterior bands of the inferior glenohumeral ligament resist torsional forces during humeral internal and external rotation, as well as becoming relatively taut during glenohumeral abduction, further adding to the stability of the joint (Armfield *et al.* 2003).

2.2.4.1.2) Dynamic Stability

Dynamic stability of the shoulder is primarily the result of coordinated neuromuscular control between the rotator cuff muscles, compressing the humeral head into the glenoid cavity, and the scapulothoracic muscles, working to ideally position the scapula (Lugo, Kung and Ma 2008).

The effect of concavity compression as a result of the tone of the rotator cuff musculature is essential during all ranges of motion, and at rest, and helps to prevent pathologic translation of the humeral head that may lead to instability; this makes the rotator cuff muscles the most important dynamic stabilizers of the glenohumeral joint (Armfield *et al.* 2003; Lugo, Kung and Ma 2008).

2.2.4.2) Movements of The Shoulder Girdle

General mobility of the shoulder complex is the result of a combination of motion at the sternoclavicular, acromioclavicular and glenohumeral joints and the gliding of the scapulothoracic joint resulting in motion of the humerus relative to the thorax; therefore, it is often useful to describe the overall combined function of the shoulder complex as motion of the humerus relative to the thorax, or thoracohumeral motion, as opposed to just motion at the glenohumeral joint (Veeger and van der Helm 2007). The majority of thoracohumeral motion occurs at the glenohumeral joint; the remainder of thoracohumeral motion occurs as a result of scapular motion relative to the thorax at the physiologic scapulothoracic joint (Veeger and van der Helm 2007; Kibler and Sciascia 2010).

Due to its ability to dynamically change its position in order to stabilize the humeral head, the scapulothoracic joint increases the amount of possible thoracohumeral motion beyond the 120° provided by the glenohumeral joint (Lugo, Kung and Ma 2008). As the shaft of the humerus elevates during abduction of the glenohumeral joint it rotates the head of the humerus in the glenoid cavity and the articular surface of the humeral head rolls along the shallow articular surface of the glenoid (Moore, Dalley and Agur 2013). Without movement of the scapula the humeral head would continue rotating in the glenoid until such a point that the articular surface of the humerus was no longer supported by the articular surface of the glenoid or the glenoid labrum; therefore, the scapula must rotate upwards in order to move the glenoid under the humeral head and provide support to the elevating upper limb (Frank *et al.* 2013; Paine and Voight 2013).

During thoracohumeral elevation, there is a combination of elevation, retraction and posterior axial rotation of the clavicle at the sternoclavicular joint, abduction of the humerus at the glenohumeral joint, and scapular internal rotation, upward rotation and posterior tilting occurring at the acromioclavicular and scapulothoracic joints (Kibler and Sciascia 2010). The coordinated movement between the scapulothoracic joint and the glenohumeral joint during thoracohumeral elevation has a fixed ratio and has been termed scapulohumeral rhythm (Lugo, Kung and Ma 2008; Kibler and Sciascia 2010). The average scapulohumeral rhythm ratio of GHJ:STJ motion throughout the entire movement of thoracohumeral elevation in healthy shoulders has a commonly accepted value of 2:1 (Lugo, Kung and Ma 2008; Kibler and Sciascia 2010; Scibek and Carcia 2012). A correct scapulohumeral rhythm is essential for effective shoulder function, with an abnormal rhythm being linked to various pathologies (Lugo, Kung and Ma 2008).

2.3) Water Polo

Water polo represents a unique combination of swimming and overhead throwing that is unlike any other sport. The complex biomechanics required in water polo may result in sport-specific adaptations that are unique to water polo players (Miller *et al.* 2018). In order to fully understand the mechanisms of development of shoulder overuse injuries amongst these athletes it is imperative to first understand the unique biomechanics required and how this may lead to sport-specific adaptations that may predispose players to the development of shoulder overuse injuries.

2.3.1) Swimming in Water Polo

Most of the swimming training performed by a water polo player is done using the freestyle stroke. When training this way, the majority of the propulsive force is generated by the upper limbs through glenohumeral internal rotation and adduction (Kluemper, Uhl and Hazelrigg 2006; Batalha *et al.* 2013; Hibberd *et al.* 2016). Three variations of the freestyle stroke are used in water polo: head-up, head-down, and head-up with the ball (De Jesus et al. 2012). Head-down freestyle represents the normal freestyle stroke, head-up is simply the normal freestyle stroke but with the head held slightly out of the water so that the player is able to look in-front of them, and head-up with the ball is the head-up variation but the player has the ball on the water in-front of the head and is pushing it forward using the wave created by the chest pushing water out of the way as the player moves forward (De Jesus et al. 2012). The following description of the biomechanics of swimming will focus on the head-down variation of freestyle as this technique is the most common variation performed by water polo players during games and trainings (De Jesus et al. 2012).

2.3.1.1) Biomechanical Analysis of The Shoulder Girdle During Freestyle

During freestyle, the athlete is prone in the water and propulsion is generated predominantly by the upper limbs, with a minor contribution from the lower limbs through a propulsive force generated by an up-down kicking movement (Heinlein and Cosgarea 2010; Pink *et al.* 2011). The freestyle stroke occurs in a cycle and can be broken down into two main phases, recovery and pull-through, with a transitional phase between each; there is an additional transitional phase in the middle of the pull-through phase that marks the transition from early to late pull-through (Heinlein and Cosgarea 2010; Pink *et al.* 2011).

2.3.1.1.1) Hand Entry

The freestyle stroke begins with the leading hand entering the water in front of the head as the arm reaches forward and glides into maximum forward flexion (Heinlein and Cosgarea 2010). As the leading arm enters the water (Figure 2.1, A), the shoulder is in forward flexion with the humerus abducted and internally rotated (Heinlein and Cosgarea 2010; De Martino and Rodeo 2018). During hand entry the scapula must facilitate the clearance of the humeral head relative to the acromion by rotating upward during forward flexion of the shoulder; the rhomboids, the upper trapezius and the serratus anterior carry out this function (Heinlein and Cosgarea 2010). During the hand entry phase the rhomboids firmly secure the superior angle of the scapula to the thorax and allow the serratus anterior and upper trapezius to create a leverage force on the scapula that results in upward rotation (Heinlein and Cosgarea 2010). The end of maximum forward flexion and the initiation of the downward movement of the hand mark the end of the hand entry phase and the beginning of the pull-through phase.

2.3.1.1.2) Pull-Through

The pull-through phase represents the phase during which the most force is generated and is broken down into early pull-through (Figure 2.1, A-B), mid pull-through (Figure 2.1, B) and late pull-through (Figure 2.1, B-C) (Pink *et al.* 2011).

The early pull-through phase follows the glide phase of hand entry and is initiated when the hand begins to move downwards and backwards in the water (Heinlein and Cosgarea 2010). During this phase, the elbow is kept high near the surface of the water allowing the pectoralis major and teres major to produce a powerful force-couple that adducts, extends and internally rotates the humerus while the latissimus dorsi and serratus anterior work hard to move the body over the relatively fixed hand, using the shoulder as a fulcrum (Heinlein and Cosgarea 2010). The early pull through phase ends with the humerus perpendicular to the torso and the hand pointing towards the floor of the pool (Heinlein and Cosgarea 2010).

The mid pull-through phase is a transitional phase between early and late pull through, during which time the arm is forward flexed 90°, perpendicular to the body, and the glenohumeral joint is moving further into extension and internal rotation as the swimmer tries to pull the arm directly backwards towards the feet (Heinlein and Cosgarea 2010).

Extension of the humerus beyond the 90° of forward flexion in the mid pull-through phase initiates the late pull-through phase as the arm continues moving backwards and begins to exit the water (Heinlein and Cosgarea 2010; Pink *et al.* 2011). During late pull-through, the serratus anterior, latissimus dorsi and pectoralis major are the most active in pulling the body over the relatively fixed hand and work hard together to extend and adduct the shoulder, with serratus anterior also assisting in rotation of the scapula and latissimus dorsi assisting subscapularis in internal rotation of the humerus (Heinlein and Cosgarea 2010; De Martino and Rodeo 2018). At the end of late pull-through the shoulder is in slight extension with the humerus adducted and internally rotated (De Martino and Rodeo 2018).

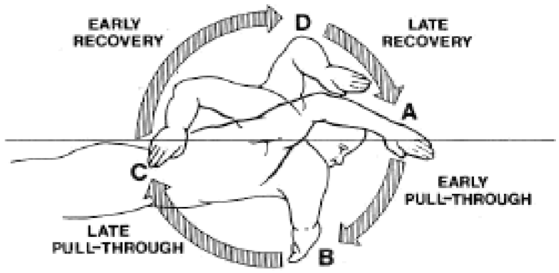

Figure 2.1: Phases of the freestyle swimming stroke cycle
(*Phases Of The Freestyle Swimming Stroke Cycle* 2020)

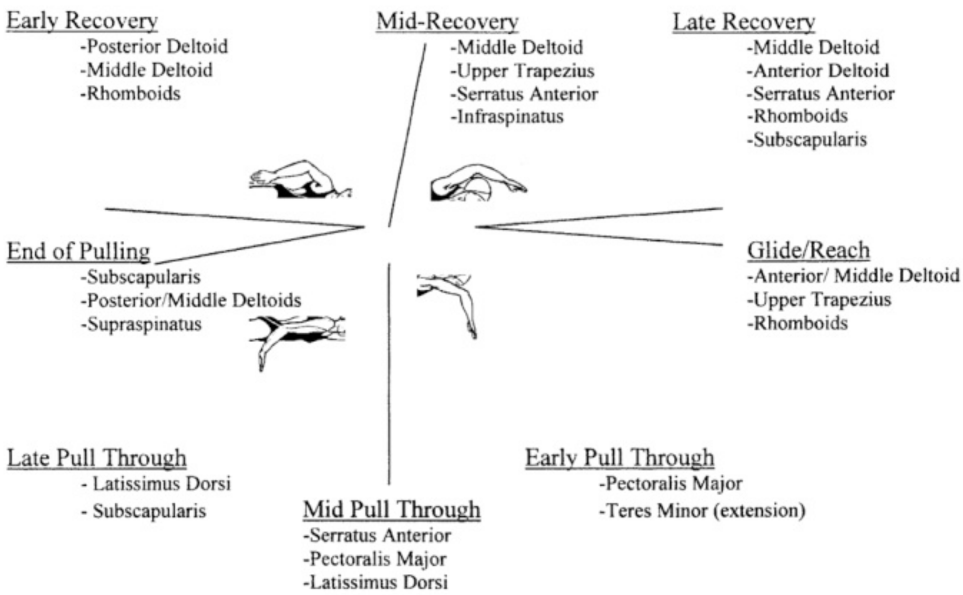

Figure 2.2: Muscle activity during the different phases of the freestyle swimming stroke
(Heinlein and Cosgarea 2010)

2.3.1.1.3) Hand Exit and Recovery

At the end of the pull through phase (Figure 2.1, C) the shoulder continues extending and the arm exits the water (De Martino and Rodeo 2018). The exit of the hand from the water initiates the recovery phase (Figure 2.1, C-D-A) as the arm is swung over-head to bring it into position to begin the pull-through phase once again (Pink *et al.* 2011). During the recovery phase the arm is completely out of the water and the humerus remains internally rotated as it is abducted and moved from extension into flexion (De Martino and Rodeo 2018). The deltoid muscle plays a major role during the recovery phase with the posterior fibers initiating the shoulder extension that lifts the arm out of the water, the middle fibers abducting the arm over-head, and the anterior fibers flexing the shoulder in preparation for hand entry (Heinlein and Cosgarea 2010; De Martino and Rodeo 2018). In addition to this, the supraspinatus assists with abduction, the upper trapezius and serratus anterior rotate the scapula upward to facilitate forward flexion, and the rhomboids retract the scapula and initiate body-roll to the opposite side in order to augment the pull-through phase of the contra-lateral arm (Heinlein and Cosgarea 2010). The recovery phase ends with the re-entry of the hand to the water in front of the head and the initiation of a new cycle.

2.3.2) Throwing in Water Polo

2.3.2.1) Factors Unique to The Water Polo Throw

The overhead throwing motion performed in water polo is unique to the sport. Though it shares several similarities to the throwing motions performed in other overhead sports such as baseball, handball or volleyball, there are a few key differences in water polo that completely change the biomechanics and kinematics of the throwing motion compared to these land-based sports. The most important, and obvious, difference is that water polo is played in an aquatic medium and, therefore, players are required to perform the throwing motion without a firm base of support from which to generate power (Alexander, Hayward and Honish 2010). As a result, the legs and the non-throwing arm must continually work to create a downward directed force throughout the throwing motion; this downward force pushes against the water which provides resistance and leads to the generation of a lift force that raises the athlete higher out of the water and transmits a small amount of energy to the trunk, similar to the ground reaction force (GRF) produced in land-based throwing, only smaller in magnitude (Alexander, Hayward and Honish 2010). The other major difference is that, in water polo, the trunk often rotates as a single unit, as opposed to performing segmental rotation (Alexander, Hayward and Honish 2010). In baseball pitching, for example, the trunk acts as a three-segment model, whereby rotation begins in the hips which is then followed by the mid-trunk and then, finally, the shoulder girdle; this segmental rotation is far more desirable as it is more efficient in generating and transferring energy from proximal to distal segments in the biomechanical chain (Alexander, Hayward and Honish 2010). Both of these factors result in a decreased ability of the lower limbs to generate energy and transmit it effectively into the throwing arm (Alexander, Hayward and Honish 2010). According to Erickson et al. (2016), if the lower limbs are not able to generate and transfer energy effectively during the throwing motion a higher demand is placed on the distal segments, such as the shoulder, to generate more velocity in order to compensate for the lack of proximal energy; this may lead to increased risk of injury development (Erickson et al. 2016).

2.3.2.2) Biomechanical Analysis of The Water Polo Throw

As a result of the lack of a stable base on which to stand while throwing, the phases of the water polo throw differ slightly from those describing land-based throwing. The phases of throwing in water polo have been loosely broken down in the literature into preparation, backswing, forward swing, ball release and follow-through (Elliott and Armour 1988; Alexander, Hayward and Honish 2010). The following description will describe the biomechanics of the throwing motion in water polo performed by a right-handed player facing the goals with the ball floating on the water to the right of the player (starting position).

2.3.2.2.1) Preparation

The first step in preparing for a throw in water polo is lifting the ball from the water. Though two methods for lifting the ball out of the water have been described in the literature – the lift from beneath method and the rotation-lift method - the use of the two methods is roughly equal amongst players and both result in the same end position with the ball resting in the players hand slightly above the water (Elliott and Armour 1988; Alexander, Hayward and Honish 2010).

2.3.2.2.2) Backswing

Once the ball has been lifted from the water, the athlete prepares for backswing. Backswing is initiated by trunk rotation that moves the throwing shoulder (right shoulder in a right-arm-dominant player) away from the target so that the left hip and shoulder are perpendicular to the target and the right arm and the ball are pointing away from the target (Elliott and Armour 1988; Alexander, Hayward and Honish 2010; Weber et al. 2014). As the end of trunk rotation is approached, the supraspinatus and deltoid vertically abduct the throwing shoulder and infraspinatus and teres minor begin moving it into external rotation as the elbow flexes slightly to lift the ball (Alexander, Hayward and Honish 2010; Weber et al. 2014). At the end of the backswing the shoulders should be in a straight line perpendicular to the target, the throwing shoulder should be near maximum external rotation with the elbow flexed between 80°-100° and the ball behind the head (Elliott and Armour 1988; Alexander, Hayward and Honish 2010). During this stage, it is imperative that the scapula is positioned in maximum retraction, upward rotation and posterior tilt; this position is essential for avoiding impingement by maintaining sufficient subacromial space as the shoulder is abducted and externally rotated (Weber et al. 2014). When the end point of the backswing is approached, the left shoulder usually abducts vertically to roughly 90° and the arm points towards the target; this sets the non-throwing arm up to initiate the forward swing phase of the throw (Alexander, Hayward and Honish 2010). Rather than to produce energy that can later be transferred into the ball, the purpose of the preparation and backswing phases is to set the player up in such a position that maximum energy may be produced during the forward swing phase that can then be transferred into the ball at release (Alexander, Hayward and Honish 2010).

2.3.2.2.3) Forward swing

The transmission of energy in the water polo throw is similar to that in other over-head throwing sports in that it follows the basic principle of energy being generated proximally and then transferred to smaller, distal segments in the biomechanical chain until, eventually, it is imparted onto the ball (Erickson et al. 2016). However, in water polo, this energy is generated predominantly by rotation of the trunk and not by ground reaction forces; this rotation initiates the forward swing phase of the throw as the trunk rotates to bring the throwing shoulder towards the target (Alexander, Hayward and Honish 2010). In addition to rotation, the trunk must also move from hyperextension into roughly 20° flexion to produce more energy (Alexander, Hayward and Honish 2010). The trunk rotation is initiated by horizontal abduction and extension of the non-throwing shoulder and occurs prior to movement of the throwing arm or shoulder which results in the throwing arm and the ball "lagging" behind the trunk; this lag is essential for the production of maximum force during forward swing as it moves the shoulder further into external rotation and puts the anterior shoulder musculature on a stretch prior to the forceful contraction that initiates the forward movement of the throwing arm, thereby increasing the potential for these muscles to produce force (Alexander, Hayward and Honish 2010). The forward movement of the throwing arm only begins as the trunk is approaching the end point of forward rotation (Alexander, Hayward and Honish 2010). The forward movement of the throwing shoulder is initiated by the pectoralis major causing horizontal adduction; the shoulder is then forcefully internally rotated by subscapularis and latissimus dorsi (Alexander, Hayward and Honish 2010; Weber et al. 2014). The elbow initially undergoes a further small amount of flexion, as a response to hand and ball motion lagging behind humeral motion, and then extends to roughly 150° at ball release (Alexander, Hayward and Honish 2010).

2.3.2.2.4) Ball Release

As the point of ball release is approached, the shoulder abducts vertically slightly, in conjunction with elbow extension, to lift the ball higher in the air (Elliott and Armour 1988; Alexander, Hayward and Honish 2010). The forearm pronates and the wrist flexes to add velocity and spin to the ball at its release (Alexander, Hayward and Honish 2010). At the point of ball release, the trunk is facing forward with the shoulders parallel to the target, the right shoulder is vertically abducted above 90°, the right elbow is nearly straight, the ball is held high above and to the side of the head, and the right forearm is inclined 10° anteriorly with regard to the vertical line drawn through the right elbow (Elliott and Armour 1988; Alexander, Hayward and Honish 2010).

2.3.2.2.5) Follow-Through

Following ball release, the throwing shoulder continues to horizontally adduct and internally rotate, the elbow continues to extend, the forearm continues pronating and the wrist continues flexing (Alexander, Hayward and Honish 2010). Initially, the velocity of the elbow and wrist increase as a result of the reduced load following ball release (Elliott and Armour 1988). The external rotators of the rotator cuff, infraspinatus and teres minor, must eccentrically contract powerfully to counteract the large internal rotation torque placed on the glenohumeral joint (Weber et al. 2014).

The tendon of the long head of the biceps is also placed under enormous strain during this time as it attempts to decelerate the horizontal adduction of the arm and prevent anterior subluxation of the humeral head (Erickson et al. 2016).

2.3.3) Adaptations of The Shoulder Girdle in Response to Water Polo

2.3.3.1) Muscle Imbalances in The Shoulders of Water Polo Players

Several studies have identified the presence of rotator cuff muscle strength imbalances in the shoulders of water polo players; this is proposed to occur as a result of the repetitive nature of the combination of swimming and overhead throwing in these athletes (Aginsky, Tracey and Neophytou 2016; Olivier and Daussin 2019). It has been found that, in water polo players, the peak performance measures of the external rotators, during both eccentric and concentric actions, were significantly decreased in the dominant arm when compared to the peak performance measures of the internal rotators (Aginsky, Tracey and Neophytou 2016; Olivier and Daussin 2019). In addition, all peak performance measures have been shown to be significantly stronger in the dominant shoulder compared to the non-dominant shoulder in water polo players, though it was noted that the ER:IR strength ratios were the same bilaterally (Olivier and Daussin 2019).

As a result of their high levels of swimming training, water polo players are prone to the development of the same, or similar, sport-specific adaptations as swimmers (Gradidge et al. 2014). The repetitive concentric contractions of the internal rotators of the arm during the propulsive phases of swimming further increases the strength of these muscles relative to the external rotators and it has been shown that, especially in healthy shoulders, swimmers have a significantly decreased ER:IR strength ratio bilaterally when compared to non-swimmers (Pollard and Croker 1999; Batalha *et al.* 2013; Struyf *et al.* 2017). This suggests that the rotator strength imbalance in the shoulders of water polo players is likely the result of the repetitive nature of swimming and is exaggerated in the dominant shoulder of these athletes as a result of the forces generated during the overhead throwing motion (Olivier and Daussin 2019).

In addition, the excessive use of the pectoral muscles for adduction of the arm during swimming leads to an increase in muscle tension with an associated decrease in muscle length; this pulls the shoulder girdle anteriorly, stretching the posterior muscles responsible for protraction of the scapula, the rhomboids and middle trapezius, and eventually resulting in lengthening and weakness of these muscles (Batalha *et al.* 2013; Laudner *et al.* 2015; Hibberd *et al.* 2016). Weakness of the rhomboids and middle trapezius leaves the anterior pull of the pectoral muscles unopposed, resulting in a more forward position of the shoulders on each side relative to their normal position (Pollard and Croker 1999; Laudner *et al.* 2015; Hibberd *et al.* 2016). It has also been found that, like swimmers, water polo players display a forward inclination of the head due to shortened cervical extensors and lengthened cervical flexors as a result of needing to keep the head above the water while using the head-up variation of freestyle (Pollard and Croker 1999; Lynch et al. 2010; Aginsky, Tracey and Neophytou 2016).

2.3.3.2) Posture of Water Polo Players

As a result of the common shoulder girdle muscle imbalances in water polo players, several authors have noted a characteristic posture in these athletes that has been described as a forward head posture with rounded shoulders (Gradidge et al. 2014; Aginsky, Tracey and Neophytou 2016). Forward head posture with rounded shoulders (FHPRS) is described as the combination of a forward inclination of the head with cervical hyperextension and a forward deviation of the shoulders (Lynch *et al.* 2010; Laudner *et al.* 2015). In their study on water polo players, Aginsky, Tracey and Neophytou (2016) found that more than 70% of the players they studied had a forward head posture and all of them displayed some degree of rounded shoulders.

As a result of these inherent postural abnormalities, the scapula becomes more protracted, with increased internal rotation, anterior tilt and downward rotation (Lynch *et al.* 2010; Laudner *et al.* 2015; Hibberd *et al.* 2016). This change in scapular position and orientation decreases the ability of the glenohumeral muscles to produce force during swimming and throwing (Pollard and Croker 1999; Borsa, Laudner and Sauers 2008; Hibberd et al. 2016). Additionally, it decreases the ability of the scapula to retract or rotate upwards, both of which are essential for clearance of the humeral head relative to the acromion during elevation of the humerus when swimming or performing the overhead throwing motion; therefore, weakness of the scapular retractors or an inability to rotate the scapula upward results in decreased swimming and throwing performance and an increased chance of developing overuse syndromes (Pollard and Croker 1999; Hibberd *et al.* 2016).

2.3.3.3) Mobility Adaptations in The Shoulders of Water Polo Players

There is an inherent contradiction in the shoulders of overhead throwing athletes in that their shoulders need to be mobile enough to be able to perform the necessary activities yet stable enough to prevent the joint from giving-way or subluxating; this contradiction was originally referred to by Wilk and Arrigo (1993) as the throwers paradox (Borsa, Laudner and Sauers 2008). As a result, altered mobility patterns have been consistently reported in overhead throwers, including water polo players (Borsa, Laudner and Sauers 2008; Keller et al. 2018; Olivier and Daussin 2019). These athletes have been repeatedly found to have a characteristic adaptation to range of motion in the throwing arm that presents as an increase in glenohumeral external rotation ROM, known as an external rotation gain (ERG), an associated decrease in glenohumeral internal rotation ROM, known as a glenohumeral internal rotation deficit (GIRD), and a decrease in horizontal adduction when compared to the non-throwing shoulder (Borsa, Laudner and Sauers 2008; Weber et al. 2014; Keller et al. 2018). In their study on baseball pitchers, Wilk et al (2011) defined GIRD as a loss of internal rotation of 20° or more in the throwing shoulder when compared to the non-throwing shoulder and went on to state that most of the throwers they observed demonstrated some degree of ERG with associated GIRD when rotational range of motion was assessed with the shoulder in 90° abduction. It must be noted that these differences apply to the rotational range of motion of the shoulder and are different to the ER:IR muscle imbalances described previously. These adaptive changes essentially shift the total motion arc of glenohumeral rotational ROM in the dominant shoulder posteriorly, allowing greater external rotation at the expense of internal rotation; this phenomenon has been referred to in the literature as a glenohumeral “rotational backshift” and may contribute to the development of overuse injuries in these athletes (Borsa, Laudner and Sauers 2008; Weber et al. 2014; Erickson et al. 2016). However, water polo players present with a unique variation of these mobility adaptations that presents as an ERG in the dominant shoulder when compared to the non-dominant shoulder and a bilaterally symmetrical GIRD (Borsa, Laudner and Sauers 2008).

Though many proposed mechanisms for the development of the rotational backshift in the shoulders of overhead athletes have been suggested, the exact mechanism of development of ERG and GIRD remain uncertain. The leading theories as to the cause of the mobility adaptations include the acquired hyper-laxity theory and the posterior shoulder immobility theory (Borsa, Laudner and Sauers 2008). The acquired hyper-laxity theory argues that the extreme abduction and external rotation of the shoulder at the end of the backswing phase of throwing gradually stretches out the anterior capsuloligamentous structures leading to a corresponding increase in the amount of external rotation possible; though, despite widespread acceptance, there is little evidence that confirms this theory (Borsa, Laudner and Sauers 2008). The posterior shoulder immobility (PSI) theory proposes that repetitive microtrauma experienced during overhead throwing leads to contracture of the posterior shoulder structures with resultant loss of glenohumeral internal rotation and horizontal adduction (Borsa, Laudner and Sauers 2008). Though there is substantial evidence that supports the development of PSI in overhead throwers, the exact cause of the immobility is not certain; it is suspected to occur either as a result of progressive tightening of the posterior capsule as a response to forceful stretching during follow-through or due to progressive tightening of the posterior rotator cuff musculature as a result of repetitive eccentric overload during arm deceleration following ball release (Borsa, Laudner and Sauers 2008).

2.3.4) Shoulder Overuse Injuries in Water Polo

In terms of water polo, the shoulder is, by far, the most commonly injured area, with incidences of shoulder pain reaching as high as 80% in the literature (Franic, Ivkovic and Rudic 2007; Galluccio et al. 2017); however, the sport-specific pathomechanics that occur in the shoulders of water polo players are not fully understood. Though there is little existing research on the exact mechanism of development of shoulder overuse injuries in water polo players specifically, several studies have been conducted that have identified a specific pattern of pathology in these athletes that consists primarily of rotator cuff injury, LHBT tendinopathy, superior labral lesions from anterior-posterior

(SLAP lesions), glenohumeral instability and shoulder impingement (both subacromial and internal) (Franic, Ivkovic and Rudic 2007; Klein et al. 2014; Galluccio et al. 2017). Interestingly, Galluccio et al (2017) found no difference in the type or incidence of shoulder overuse injuries between the premier and second division water polo players in their study.

Another common diagnosis for shoulder pain in water polo players is the clinical syndrome of swimmers' shoulder; swimmers' shoulder encompasses many of the same pathologies found in water polo players, but the mechanism of development is very different (Franic, Ivkovic and Rudic 2007; Borsa, Laudner and Sauers 2008). Due to the lack of repetitive throwing forces in the <u>non-dominant</u> shoulders of water polo players, it is likely that the overuse injuries that develop in these shoulders occur as a result of the continuous microtrauma of swimming and may indeed constitute swimmers' shoulder. However, it is more likely that the shoulder overuse injuries observed in the <u>dominant</u> shoulders of water polo players are the result of the ballistic forces of overhead throwing occurring in the presence of the existing biomechanical changes that predispose these athletes to the development of swimmers' shoulder. Therefore, in order to accurately understand how overuse injuries develop in the dominant shoulders of water polo players, and how this differs from the non-dominant shoulder, it is important to first understand the development of swimmers shoulder - in either shoulder - and how this process may subsequently be affected by the unilateral forces of overhead throwing that result in the characteristic group of shoulder overuse injuries observed in the dominant shoulders of water polo players.

2.3.4.2) Mechanisms of Injury in Water Polo

2.3.4.2.1) Swimmers Shoulder

Swimmers shoulder is the term used to describe the complex problem of shoulder pain in swimmers; it is considered a clinical syndrome and, therefore, does not have an established diagnosis (Almeida et al. 2011; Struyf et al. 2017; De Martino and Rodeo 2018). However, according to most authors, there are usually three musculoskeletal dysfunctions that collectively constitute swimmers' shoulder: glenohumeral joint instability, subacromial impingement and tendonitis of the rotator cuff or, occasionally, the LHBT (Pollard and Croker 1999; Heinlein and Cosgarea 2010; Sein et al. 2010; Hibberd et al. 2016). It is the overlap of these dysfunctions with those found in water polo players that has caused some of the confusion with regards to the accurate diagnosis of shoulder pain in water polo players.

It is possible that swimmers' shoulder may occur as a result of repetitive, forceful over-head activity that stretches out the antero-inferior capsuloligamentous structures leading to laxity of the joint that predisposes to the development of instability, as originally described by Jobe et al (1989), though, according to Sein et al (2010), there is little evidence that either supports or refutes this theory. The impingement that occurs in swimmers' shoulder is described as a secondary subacromial impingement (SAI) (Tovin 2006; Pink et al. 2011; De Martino and Rodeo 2018). It is proposed that the characteristic swimmers' posture of a forward head with rounded shoulders, combined with the altered kinematic patterns it results in, causes a decrease in subacromial space distance (Pink et al 2011), as pointed out by Hibberd et al (2016) who found significant decreases in the subacromial space distance in the shoulders of competitive swimmers when compared to non-overhead athletes over a training season. In addition, Hibberd et al (2016) also found a significant negative correlation between changes in subacromial space distance and changes in forward shoulder posture, meaning that, as forward shoulder posture increased, subacromial space decreased. These changes in subacromial space distance increase the risk of developing impingement by increasing the rate of contact between the rotator cuff tendons, in particular the supraspinatus tendon, and the coraco-acromial arch (Hibberd et al. 2016). However, in their study, Sein et al (2010) propose an alternate theory as to the high incidences of impingement and tendonitis in swimmers; in this theory, repetitive overuse results in tendonitis of the supraspinatus with an increase in tendon thickness as a result of the inflammatory process, this increased thickness leads to a decrease in the subacromial space and a subsequent increase in the risk of development of subacromial impingement (Sein et al. 2010).

2.3.4.2.2) Instability

It is possible that water polo players are also susceptible to the joint instability complex described by Jobe et al (1989); however, this effect would be more pronounced in the throwing shoulders of these athletes when compared to the shoulders of swimmers. In addition to the tensile stress created in the IGHL as a result of glenohumeral abduction and external rotation during the backswing phase of throwing, it has been proposed that the rotational backshift in the dominant shoulders of overhead throwers greatly increases the amount of stress on this ligament with subsequent stretching and attenuation of the anterior capsuloligamentous structures that may result in symptomatic instability that is more apparent than that in swimmers (Gelber, Soloff and Schickendantz 2018; Miller et al. 2018). This would explain why, despite the fact that swimming does not directly increase glenohumeral joint laxity (Heinlein and Cosgarea 2010; Struyf et al. 2017), instability is still commonly reported in the shoulders of water polo players (Franic, Ivkovic and Rudic 2007; Webster, Morris and Galna 2009; Galluccio et al. 2017). Furthermore, the constant use of the rotator cuff muscles during swimming and overhead throwing makes these dynamic stabilisers prone to fatigue, with resultant excessive humeral head translation that worsens with continued activity (Borsa, Laudner and Sauers 2008; Gelber, Soloff and Schickendantz 2018).

2.3.4.2.3) Impingement

The two most commonly reported types of impingement in water polo players are secondary subacromial impingement and internal impingement, with Galluccio et al (2017) finding an incidence of impingement of 21.43% in water polo players, though they did not specify whether this was SAI or internal impingement (Franic, Ivkovic and Rudic 2007; Klein et al. 2014; Galluccio et al. 2017).

Internal impingement in overhead throwers has been described as impingement of the posterior aspect of the supraspinatus tendon insertion and the superior aspect of the infraspinatus tendon insertion into the greater tuberosity, caused through mechanical compression between the postero-lateral portion of the greater tuberosity and the postero-superior aspect of the glenoid during the extremes of abduction and external rotation during the late stages of the backswing phase of throwing (Franic, Ivkovic and

Rudic 2007; Gelber, Soloff and Schickendantz 2018). In their study, Klein et al (2014) reported increased incidences of infraspinatus and posterior labrum lesions in the throwing shoulders of water polo players and concluded that, in symptomatic players, postero-superior internal impingement of the rotator cuff appeared to be the main cause of shoulder pain.

However, the shoulders of water polo players are still susceptible to the effects of subacromial impingement as a result of their unique sport-specific adaptations. The posture of these athletes results in a protracted position of the scapula with a decreased ability to rotate upward (Lynch et al. 2010; Hibberd et al. 2016; Miller et al. 2018). It has also been shown that the ability of the scapula to rotate upwards decreases significantly following an intense water polo training session (Miller et al. 2018). This decreased ability of the scapula to rotate upwards increases the rate of contact between the supraspinatus tendon and the under surface of the coraco-acromial arch, leading to subacromial impingement (Miller et al. 2018).

2.3.4.2.4) Rotator Cuff Injury

Rotator cuff injury (RCI) represents the most common pathology noted in the shoulders of water polo players, with Galluccio et al (2017) reporting an incidence of 21.43% in the dominant arm and an incidence as high as 38.1% when assessing players bilaterally. Rotator cuff injury in water polo players presents predominantly as tendonitis or partial- or full-thickness tears, usually involving supraspinatus and infraspinatus and, occasionally, subscapularis; involvement of teres minor does occur but is much less frequent (Franic, Ivkovic and Rudic 2007; Klein et al. 2014; Galluccio et al. 2017). There are two main theories as to the high incidence of rotator cuff injury in water polo players. The first, and most common theory, is that repetitive compression of the rotator cuff tendons over time, as a result of subacromial or internal impingement, leads to inflammation of the tendons in the area of the compression with resultant tendonitis and pain (Klein et al. 2014; Gelber, Soloff and Schickendantz 2018). In the case of posterior internal impingement, the player will present with posterior cuff pain that is aggravated when the shoulder is abducted to 90° and maximally externally rotated (Gelber, Soloff and Schickendantz 2018). In the case of SAI, the player will present with pain on the superior aspect of the shoulder, near the coraco-acromial arch, that is worse with shoulder elevation or combined horizontal adduction and internal rotation (Sein et al. 2010; Ludewig and Braman 2011). The second theory for the cause of RCI in water polo players involves the movements of the rotator cuff muscles throughout the throwing motion. At the end of the backswing phase, when the shoulder is in abduction and maximum external rotation, the posterior cuff muscles are twisted and compressed; this is suddenly reversed as forward-swing is initiated and the posterior cuff muscles are rapidly stretched out, generating tensile stress within these muscles (Gelber, Soloff and Schickendantz 2018). This tensile stress is greatly increased during the follow-through phase as a result of the necessity for the posterior cuff muscles to eccentrically contract in order to rapidly decelerate the arm following ball release (Gelber, Soloff and Schickendantz 2018). This repetitive twisting and pulling can, over time, result in tendon failure ranging from tendonitis to occasional full-thickness tears (Gelber, Soloff and Schickendantz 2018).

The second theory mentioned compliments the theory proposed by Sein et al (2010) when explaining the high incidences of supraspinatus tendonitis in swimmers with swimmers' shoulder. Together, these two theories indirectly propose a mechanism for rotator cuff injury in water polo players that starts with overuse of the rotator cuff muscles as a result of continuous swimming and repetitive overhead throwing (Sein et al. 2010; Gelber, Soloff and Schickendantz 2018). This overuse causes an inflammatory response within the supraspinatus tendon that constitutes tendonitis and results in swelling of the tendon; this swelling decreases the subacromial space distance and increases the rate of mechanical compression of the supraspinatus tendon under the coraco-acromial arch, leading to an increased chance of SAI developing in these athletes and further exacerbating the rotator cuff injury (Sein et al. 2010; Gelber, Soloff and Schickendantz 2018).

2.3.4.2.5) Long Head of The Biceps and Glenoid Labrum Injury

Tendonitis of the long head of the biceps and associated lesions of the glenoid labrum are frequently observed in the shoulders of water polo players, with incidences of LHBT tendonitis in symptomatic players reaching as high as 48% (Franic, Ivkovic and Rudic 2007; Galluccio et al. 2017). Similar to RCI, two different theories have been proposed with regards to the development of these pathologies. The first theory proposes a peel-back mechanism of injury, whereby the abduction and maximum external rotation at the end of backswing causes the LHBT to move posterior to the joint; the tendon is unable to resist the torsional force generated by this position which may lead to failure of the biceps anchor, allowing the tendon to "peel" the superior aspect of the labrum away from the glenoid rim resulting in a SLAP lesion (Franic, Ivkovic and Rudic 2007; Gelber, Soloff and Schickendantz 2018). The second theory proposes that the LHBT also plays a significant role in the deceleration of the arm during the follow-through phase of throwing, with enormous strain being placed on the tendon as it attempts to dissipate the forces generated during forward-swing and prevent anterior subluxation of the humeral head; it is believed that this may lead to SLAP lesions as the tendon pulls the labrum away from the glenoid rim as it is forcefully loaded (Erickson et al. 2016).

2.4) Conclusion

The shoulders of water polo players are unique in that both shoulders undergo different forces; the non-dominant shoulder undergoes only the continuous micro-trauma of swimming whilst the dominant shoulder undergoes both the continuous micro-trauma of swimming as well as the explosive forces of overhead throwing (Borsa, Laudner and Sauers 2008). As a result, the shoulders of these athletes present with a unique mobility adaptation profile (Borsa, Laudner and Sauers 2008). These unique mobility adaptations set up a peculiar contradiction in the description of the overall sport-specific adaptations that occur in the shoulders of water polo players. On the one hand, the effects of overhead throwing result in a glenohumeral rotational backshift in the dominant shoulders of these players that favours external rotation at the expense of internal rotation and horizontal adduction (Borsa, Laudner and Sauers 2008; Keller et al. 2018). On the other hand, bilateral over-development of the latissimus dorsi, infraspinatus and pectoralis major and minor muscles, as a response to swimming, results in an ER:IR muscle imbalance and a forward head posture with rounded shoulders, all of which favour internal rotation and horizontal adduction at the expense of external rotation (Gradidge et al. 2014; Aginsky, Tracey and Neophytou 2016; Olivier and Daussin 2019). This contradiction is scarcely discussed in the literature and may play a significant role in the correct description of the mechanisms of shoulder overuse injury in water polo players.

The bilateral differences in the shoulders of water polo players allow researchers the opportunity to gain a better understanding of the mechanism of development of shoulder overuse injuries in these athletes. By assessing the non-dominant shoulders, researchers can determine the effects that swimming may be having on the dominant shoulder and develop a baseline reference for the mobility adaptations that occur exclusively in response to swimming. The dominant shoulder can then be assessed for these same adaptations and, using the non-dominant shoulder as a reference, it can be extrapolated what specific role the overhead throwing motion plays in the development of the mobility adaptations found in the dominant shoulders of water polo players and how this may lead to the development of the unique set of shoulder overuse injuries encountered in these athletes.

CHAPTER THREE
METHODOLOGY

3.1) Introduction

This chapter will provide an in-depth description of the research process performed in this study. In doing so, this chapter will discuss the study design and the approval granted to the study, participant recruitment, sampling method, study setting, measurement tools, the research procedure, and the analysis of the data collected, as well as going over the ethical considerations relevant to this study.

3.2) Study Design and Approval

The study involved a single assessment of the shoulders of male first division water polo players in order to assess the range of motion, posture and presence of overuse injuries in each shoulder and then compare the two shoulders. The study utilised a quantitative paradigm with no intervention. Therefore, a comparative descriptive study design was used to compare the dominant and non-dominant shoulders of the participants (Brink 2012: 96-118). This allowed the researchers to describe the individual variables in each shoulder as well as the differences between the two shoulders (Brink 2012: 96-118).

This study was approved by the Durban University of Technology Institutional Research Ethics Committee (Ethical Clearance number 011/20). Once permission had been granted by the clinic director (Appendix E), the research supervisor (Appendix L), and the Acting Director: Research and Postgraduate Support (Appendix D), data collection took place at the Durban University of Technology Chiropractic Day Clinic (on-campus data collection site) and at the practice of the research supervisor, Dr G Matkovich (360 Clark Road, Glenwood, Durban) (off-campus data collection site).

3.3) Study Population

The study population consisted of males between the ages of 18 and 45 who participate in the KZN mens first division water polo league. This population was chosen due to the high levels of shoulder overuse injuries reported in other players of a similar level of play with similar demographics (Franic, Ivkovic and Rudic 2007: 281-287).

3.4) Participant recruitment

Participants were recruited through the distribution of a flyer (Appendix C) by the researcher on social media and via word of mouth. Flyers were only distributed by the researcher following approval from the Durban University of Technology's Institutional Research Ethics Committee (IREC) (Appendix K). Individuals who respond to the advertisement were then screened via a telephonic interview to assess their eligibility to participate in the study. The telephonic interview consisted of the following questions:

	Questions:	Expected Answers:
1	What is your age?	18-45
2	Do you play water polo?	Yes
3	What division do you play in?	1st division
4	What club do you play water polo for?	DHS old boys, Clifton, Glenwood Old Boys, Varsity College or Queens Park
5	Do you currently have any upper limb musculoskeletal pain or injuries? E.g. Sprains/strains, adhesive capsulitis, broken bones, neurological deficits, etc	No

Table 3.1: Telephonic interview questions

3.5) Sampling

3.5.1) Sample Size

The study population consisted of approximately 50 individuals. Previous research (Franic, Ivkovic and Rudic 2007: 281-287; Galluccio *et al.* 2017: 1) has indicated that the prevalence of shoulder overuse injuries in this population would be approximately 60%. Therefore, the statistician recommended a sample that consisted of a minimum of 33 males who compete in the KZN mens 1st division water polo league and met the inclusion criteria (Esterhuizen 2020). According to the statistician, a sample size of 33 allowed a 10% precision margin in the estimation of the true population prevalence for a 95% confidence interval (Esterhuizen 2020).

3.5.2) Sampling Technique

Due to the small size of the population, as well as financial and time constraints, convenience sampling was used in this study (Brink 2012: 140). This meant that all prospective participants who responded to the flyer (Appendix C) by contacting the researcher, and who meet the inclusion and exclusion criteria, were allowed to take part in the study. This allowed the researcher to get the largest sample size possible while still keeping the data homogenous through the use of the inclusion and exclusion criteria (Brink 2012: 140).

3.5.3) Sample Characteristics

In order for the prospective participants to be included into the study, they had to meet the following criteria:

3.5.3.1) Inclusion Criteria

1. Participants must be male in order to ensure homogeneity in the sample population (Clayton 2018: 2-5)
2. Participants must currently participate in the KZN mens 1st division water polo league
3. Participants must not have any current upper limb musculoskeletal injury or pain

3.5.3.2) Exclusion criteria

1. Any participant with an upper limb musculoskeletal injury or pain
2. Any participant under the age of 18 as parental consent would be required
3. Any participant over the age of 45 as natural degenerative changes may influence results (American-Academy-of-Orthopaedic-Surgeons 2013: para. 10)
4. Any participant who refused to sign the letter of informed consent

3.6) Study Setting

The setting of the study was the KZN mens 'first division water polo league. The mens ' first division water polo league is the premier open mens water polo division in South Africa and consists of the top club teams from around the country who participate in provincial leagues against each other. The players who participate in the league are some of the highest level water polo players in the country, with many teams in the KZN league consisting of multiple provincial and national level players. The seasons usually run in the summer and are broken into two portions, one from January to April and one from September to December, with a four-month break in the middle over the winter period. Although there is a break in winter, most players keep up moderate levels of water polo training in order to be able to return at full fitness level and some even compete in a winter league. Due to the high levels of performance of the first division, during the season most players train approximately three times a week for at least one hour each session, with a minimum of one game a week (which also lasts approximately one hour). On top of this, players normally participate in at least one national club tournament a year and may also be recruited for provincial and national teams, which require even higher levels of training and even more tournaments.

3.7) Measurement tools

3.7.1) Validity and Reliability

In order to maintain rigour and ensure that the quality of the study was as high as possible, the researcher ensured that all of the measurement tools used in the study were valid and reliable (Norkin and White 2009; Hébert-Losier and Abd Rahman 2018; Senthil *et al.* 2018b). All of the measurement tools used in the study were calibrated prior to the testing procedure. All of the orthopaedic tests used in the study have been found to be valid and reliable, as well as having acceptable sensitivity and specificity (Kim *et al.* 2001; Lo *et al.* 2004; Michener *et al.* 2009; Hegedus *et al.* 2012; Itoi 2013; Eshoj *et al.* 2018; Clark *et al.* 2019). In order to ensure reproducibility of the results, each participant was given the same set of instructions prior to the beginning of the testing procedure and the procedure was carried out in the same order for each participant (Brink 2012: 97).

3.7.2) PosturePro 8 software

PosturePro is a commercially available postural analysis software used for the photographic analysis of posture. According to Senthil *et al.* (2018a: 2), as well as Hébert-Losier and Abd Rahman (2018: 483-494), the PosturePro 8 Software (PPS8) is an effective and reliable method of analysing posture. For this study the PPS8 was used to measure the degree of forward head carriage, by measuring the craniovertebral angle, and forward shoulder posture, by measuring the acromiovertebral angle. The software was loaded onto a laptop and was used in conjunction with a digital camera.

3.7.3) Digital camera

A digital camera was used to take the photographs required for the posture assessment. The camera was placed on a tripod 1m high and 3.5m away from the wall. The participants were required to stand 40cm away from the wall, which was marked on the floor with tape. This was in line with the procedure set out by Thigpen *et al.* (2010: 702) and was performed in order to ensure that the measurements taken from each photo were accurate and reproducible.

3.7.4) Goniometer

Both active and passive joint range of motion were measured for each relevant motion using a universal goniometer in order to assess for any hyper- or hypo-mobility. Norkin and White (2009: 39-44) found standard universal goniometers to have good validity and good-to-excellent reliability in measuring both fixed joint angles as well as joint range of motion. All range of motion measurements were performed passively. The researcher provided scapular stabilisation during the procedure in order to isolate glenohumeral motion. All measurements were performed bilaterally according to the procedure set out by Norkin and White (2009: 68-89) and Borsa, Laudner and Sauers (2008: 27), all of which have been found to have acceptable validity. The following glenohumeral joint motions were assessed: internal rotation, external rotation and horizontal adduction.

3.7.5) Shoulder Overuse Injury tests

Shoulder orthopaedic testing was used to diagnose any underlying overuse injuries. For the purpose of statistics, each injury was quantified as either positive or negative based on the outcome of the tests described below. All tests were performed bilaterally.

For the purpose of this study, rotator cuff injury was assessed according to Michener *et al.* (2009: 1901); Hegedus *et al.* (2012: 974-978) and Itoi (2013: 198); where less than 3 out of 5 tests being positive indicated an impingement syndrome and 3 or more positive tests indicated a tendonitis; no positive tests would indicate a negative result for rotator cuff injury. The following 5 tests were used to assess for rotator cuff injury:

3.5.7.1) Empty Can test

This test was identified as being 70% accurate when detecting tears of the supraspinatus tendon (Itoi 2013: 199).

3.5.7.2) Painful Arc test

This test has a sensitivity of 53% and a specificity of 73% when used to detect rotator cuff injury (Hegedus *et al.* 2012: 976).

3.5.7.3) Hawkins-Kennedy test

This test has a sensitivity of 79% and a specificity of 59% when detecting supraspinatus injury (Hegedus *et al.* 2012: 976).

3.5.7.4) External Rotation Resistance test

This test was found to have the best positive likelihood ratio (+LR of 4.39) for detecting subacromial impingement (Michener *et al.* 2009: 1900).

3.5.7.5) Neer test

This test was found to be 72% sensitive and 60% specific for detecting rotator cuff injury (Hegedus *et al.* 2012: 976).

Due to the fibres of the long head of the biceps blending with the glenoid labrum at its origin, these two structures are interdependent and are therefore frequently injured together as stress on the long head of the biceps is inevitably shared with the glenoid labrum (Kim *et al.* 2001: 162; Mehl 2018: 76) (Hegedus *et al.* 2012: 966). As a result, LHBT and glenoid labrum injury were assessed together using two tests, with either test being positive indicating the presence of LHBT and/or labral injury. The glenoid labrum and the long head of the biceps were assessed using the following tests:

3.5.7.6) Yergasson's test

This test was found to be 95% specific for identifying biceps tendinopathy (Hegedus *et al.* 2012: 975).

3.5.7.7) Biceps Load test II

This test was found to be 89.7% sensitive and 96.6% specific for detecting SLAP type 2 injuries (Kim *et al.* 2001: 162; Clark *et al.* 2019: 347-349).

The final pathology assessed for was anterior instability of the glenohumeral joint.

3.5.7.8) Apprehension-Relocation-Surprise test

This test was found to have a sensitivity of 63.89% and a specificity of 98.91% for detecting anterior shoulder instability (Lo *et al.* 2004: 303; Eshoj *et al.* 2018: 6).

3.8) Research Procedure

After participants were found to be eligible to be included in the study following the initial telephonic screening interview, an appointment was scheduled at their earliest convenience, either at the Durban University of Technology Chiropractic Day Clinic (on-campus data collection site) or at the practice of the research supervisor (off-campus data collection site).

Upon arrival to the initial consult at the Chiropractic Day Clinic, participants were given a letter of information (Appendix A) and asked to sign a letter of informed consent (Appendix B). Those who chose not to sign the letter of informed consent were not included in the study and were thanked and allowed to leave. Each participant then underwent a case history (Appendix F), a general physical examination (Appendix G) and a shoulder regional examination (Appendix H) to determine their eligibility to be included in the study. Following this, eligible participants began with the sport-specific shoulder examination.

3.8.1) Shoulder Range of Motion Assessment

The participants were instructed to remove their shirt and lie supine on the examination table for the range of motion examination. Passive range of motion was measured bilaterally, with stabilisation of the scapula to isolate glenohumeral motion (Norkin and White 2009: 68-89). The following glenohumeral motions were assessed as described below: external rotation in 90^{o} abduction, internal rotation in 90^{o} abduction, horizontal adduction. The range of motion assessment was divided into dominant and non-dominant sides, with the researcher performing all of the measurements in the dominant shoulder before moving on to the non-dominant shoulder.

3.8.1.1) External Rotation

Test position:

-Participant is supine with the test arm in 90^{o} of glenohumeral abduction

-The forearm is flexed to 90^{o} so as to be perpendicular to the examining surface

-The forearm is in neutral supination and pronation with the palm facing the feet of the participant

-A supporting pad is placed under the length of the humerus such that the long axis of the humerus is in line with the acromion

-The researcher supports the elbow of the participant to maintain 90^{o} abduction and neutral horizontal adduction and abduction

-The spine of the scapula is stabilized to prevent unwanted motion

-The humerus is rotated externally through the full range of glenohumeral external rotation while maintaining the 90^{o} elbow flexion and 90^{o} glenohumeral abduction

-The end point of glenohumeral external rotation is the point where resistance is encountered and further motion results in scapular posterior tilting or retraction

Goniometer position:

-Fulcrum centred over the olecranon process
-Proximal arm aligned parallel to the examining surface
-Distal arm aligned to the long axis of the ulna

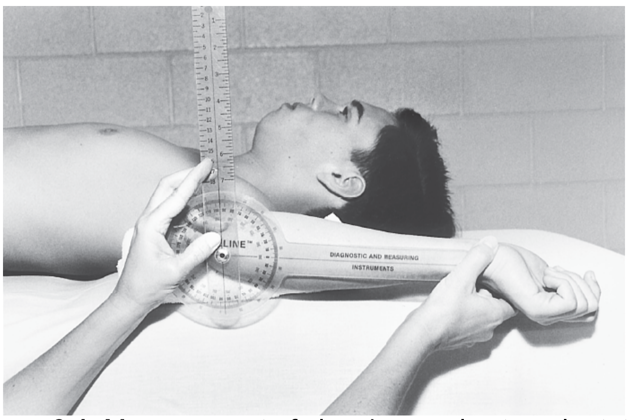

Figure 3.1: Measurement of glenohumeral external rotation
(Norkin and White 2009)

3.8.1.2) Internal rotation

Test position:

-The participant is set up as for the external rotation measurement

-The anterior clavicle, acromion and coracoid are stabilized to prevent unwanted scapular motion

-Once in position the humerus is rotated internally through the full range of glenohumeral internal rotation

-The end point of glenohumeral internal rotation is the point where resistance is encountered and further motion results in scapular anterior tilting or protraction

Goniometer position:

-Fulcrum over olecranon process

-Proximal arm aligned parallel to the examining surface

-Distal arm aligned to the long axis of the ulna

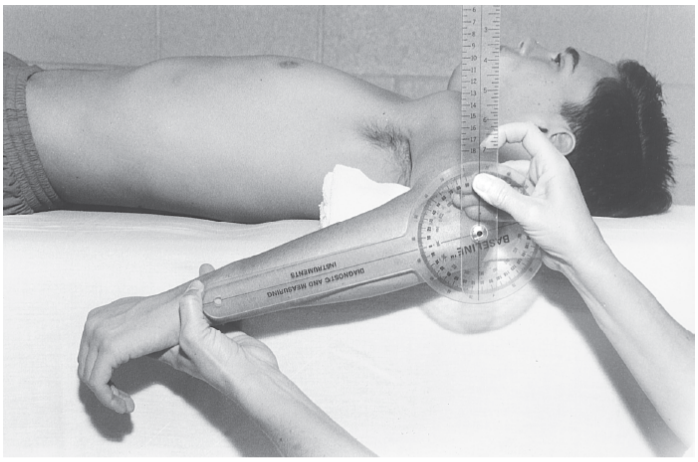

Figure 3.2: Measurement of glenohumeral internal rotation
(Norkin and White 2009)

3.8.1.3)) Horizontal adduction test

Test position:

-The participant is set up as for the internal/external range of motion testing

-The researcher stabilizes the involved scapula by grasping the lateral border in order to prevent unwanted motion

- The proximal forearm is grasped and the humerus is moved through the full range of glenohumeral horizontal adduction

-The end point of glenohumeral horizontal adduction is the point where resistance is encountered and further motion results in scapular lateral translation and internal rotation

Goniometer position:

-Fulcrum centred over acromion process

-Proximal arm aligned parallel to examining surface

-Distal arm aligned to posterior midline of humerus

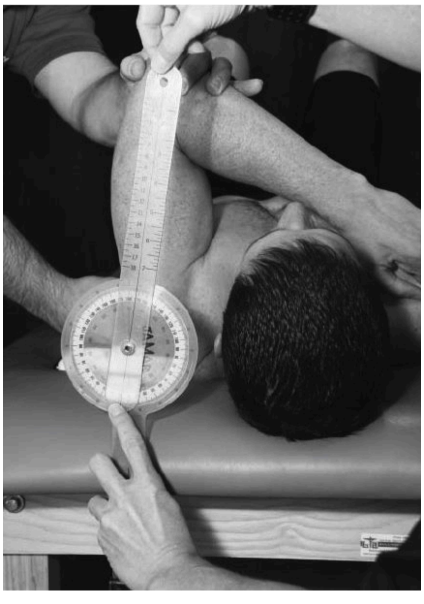

Figure 3.3: Measurement of glenohumeral horizontal adduction
(Garrison et al. 2012)

Following the range of motion testing, the participants underwent a sport-specific shoulder overuse injury assessment in order to identify any underlying pathology.

3.8.2) Shoulder Injury Assessment

This examination focused only on the pathologies relevant to water polo, as identified by Galluccio *et al.* (2017: 1); Franic, Ivkovic and Rudic (2007: 283-284); Hams *et al.* (2019: 129); Miller *et al.* (2018: 369-374) and Mountjoy, Miller and Junge (2019: 1-7). These included rotator cuff injury, long head of biceps and labrum injury and anterior glenohumeral instability. During this assessment, each test was performed on the dominant shoulder and then the non-dominant shoulder before the researcher moved on to the next test.

The following tests were used to assess for rotator cuff injury:

3.8.2.1) Empty can test

This test is performed with the participant in a seated position. A downward force is applied to the involved arm which is held in 90^{o} of scaption (30^{o}-40^{o} anterior to the coronal plane) and internally rotated (with the thumb towards the floor). A positive test is indicated by pain in the region of the rotator cuff or weakness when compared to the unaffected side (Itoi 2013: 199).

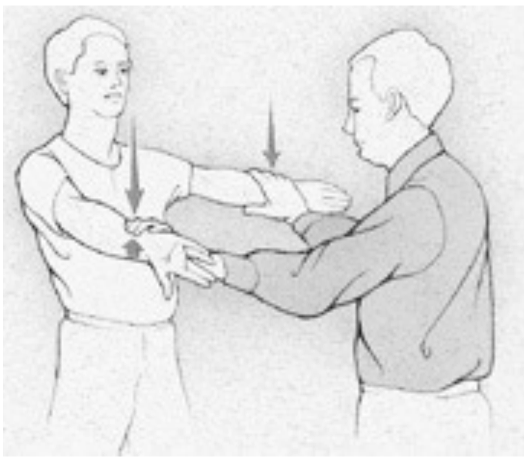

Figure 3.4: Empty can test
(Woodward and Best 2000)

3.8.2.2) Painful Arc test

This test is performed with the participant standing. The participant actively abducts their arm through the full range of motion in vertical abduction and then slowly lowers it down to the neutral resting position. A positive test is indicated by pain during elevation between 60^{o} and 120^{o}, and during depression between 90^{o} and 30^{o} (Itoi 2013: 198) (Michener *et al.* 2009: 1899).

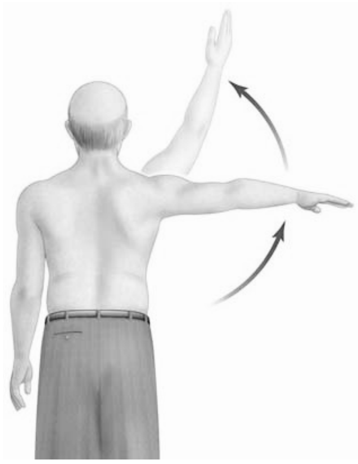

Figure 3.5: Painful arc test
(Physiopedia 2019)

3.8.2.3) Hawkins-Kennedy test

This test is performed with the participant seated. The affected arm is held in 90^{o} of forward flexion, flexed to 90^{o} at the elbow, and internally rotated. A positive test is indicated by pain in the region of the subacromial space or supraspinatus tendon (Itoi 2013: 199) (Michener *et al.* 2009: 1899).

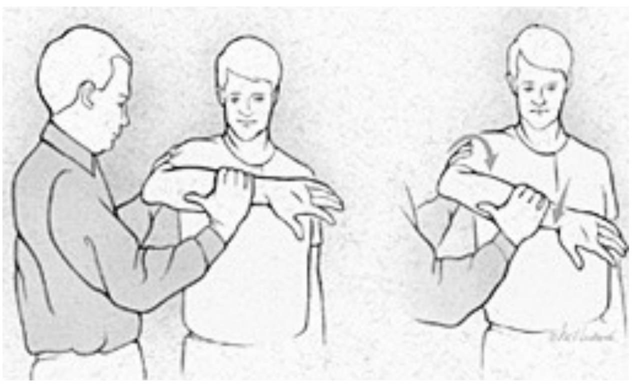

Figure 3.6: Hawkins-Kennedy test
(Churgay 2009)

3.8.2.4) External Rotation Resistance test

This test is performed with the patient seated. The affected arm is held at the side with the elbow in 90° flexion while the examiner applies a lateral-to-medial force on the distal forearm to resist external rotation of the shoulder. A positive test is indicated by pain in the shoulder or weakness when compared to the unaffected side (Michener *et al.* 2009: 1899) (Itoi 2013: 199).

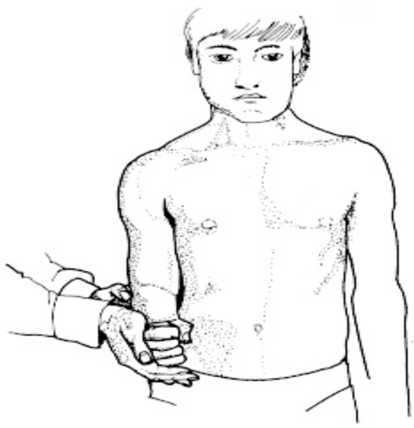

Figure 3.7: External rotation resistance test
(Doherty and Doherty 1992)

3.8.2.5) Neer test

This test is performed with the participant seated. The examiner stabilizes the affected scapula with a downward force applied to the superior aspect of the scapula while passively flexing the affected shoulder maximally by holding the ipsilateral wrist and lifting the arm through the full range of shoulder forward flexion. A positive test is indicated by the production of pain over the superior aspect of the shoulder (Michener *et al.* 2009: 1899) (Itoi 2013: 199).

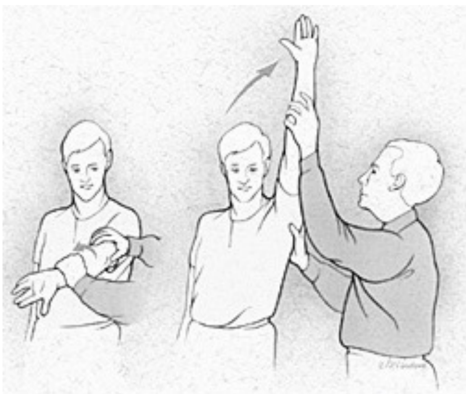

Figure 3.8: Neer test
(Churgay 2009)

The following test was used to assess the long head of the biceps:

3.8.2.6) Yergason's Test

This test is performed with the participant seated. The affected arm is held at the side with the elbow flexed to 90^o and the forearm in pronation. The examiner holds onto the distal forearm and resists as the participant is asked to simultaneously externally rotate the shoulder and supinate the forearm. A positive test is indicated by pain in the region of the bicipital groove or weakness when compared to the unaffected side (Harris and Ali 2014: 20).

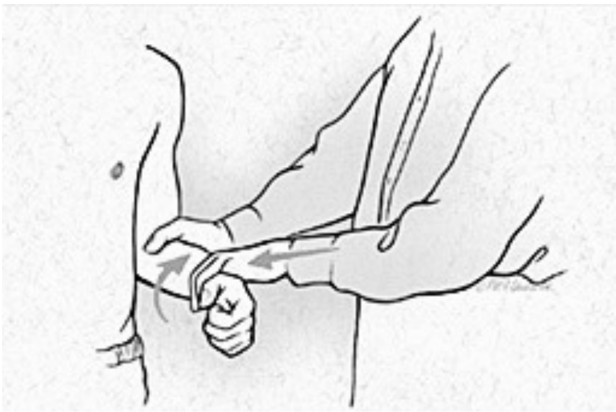

Figure 3.9: Yergason's test
(Churgay 2009)

The following test was used to assess the glenoid labrum:

3.8.2.7) Biceps Load test II

This test is conducted with the participant lying supine, the affected arm flexed to 90^o at the elbow and the forearm supinated. The examiner grasps the participant's elbow and wrist on the ipsilateral side and abducts the arm to 120^o in the coronal plane whilst maximally externally rotating the humerus. The participant is then instructed to flex the elbow further while the examiner resists this flexion. A positive test is indicated by the production of pain, or an increase in the level of pain, during the resisted elbow flexion part of the test (Kim *et al.* 2001: 161; Pandey *et al.* 2014: 29).

Figure 3.10: Biceps load test II
(Churgay 2009)

The last test was used to assess for anterior glenohumeral instability:

3.8.2.8) Apprehension-Relocation-Surprise test

This test is performed with the participant supine and comprises 3 steps. The first step is the apprehension step and is performed by the examiner taking the participants shoulder into 90° abduction in the coronal plane. The participant's elbow is flexed to 90° and is rested on the examiners knee with the shoulder in neutral flexion and extension. The examiner then uses a light force to gently move the shoulder into maximal external rotation. A positive for this step is indicated by the participant reporting a stretch, pain or apprehension. The next step is the relocation step. This is performed by the examiner decreasing the external rotation slightly, applying an anterior-to-posterior force through the proximal humerus, and then externally rotating the shoulder again. A positive for this step is indicated by the patient reporting a decrease of symptoms elicited during the apprehension step, or by an increase in external rotation. The final step is the surprise step. This step is performed by the examiner quickly, and unexpectedly, removing the force from the proximal humerus. A positive for this step is indicated by the reproduction of the symptoms elicited during the apprehension step (Lo *et al.* 2004: 302-303; Eshoj *et al.* 2018: 3).

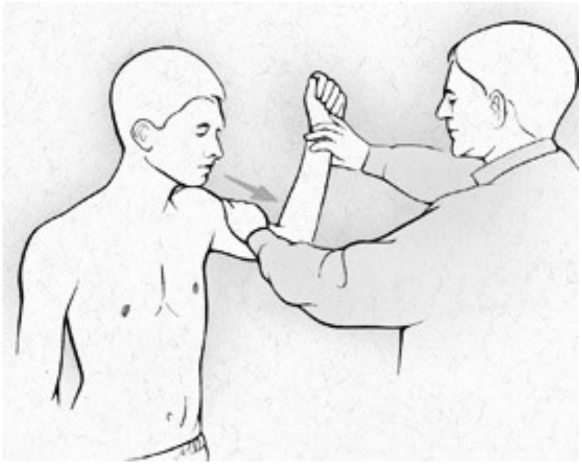

Figure 3.11: Apprehension-Relocation-Surprise test
(Woodward and Best 2000)

3.8.3) Shoulder Posture Assessment

Following the completion of the orthopaedic testing, the participants began the posture assessment. The researcher measured the participants acromiovertebral angles and craniovertebral angles bilaterally using the PPS8 software.

Reflective markers were placed bilaterally over the C7 spinous process and the acromion. The participants were placed in front of the camera so that they were facing perpendicular to the line of sight of the camera (i.e in a lateral position) with their foot closest to the wall lined up to the 40cm marker on the floor. The participants were then instructed to bend down and touch their toes three times, reach overhead three times and then assume a natural standing position (Thigpen *et al.* 2010: 702). One photo was taken of each side of the participants and they were required to perform this process before each photo was taken (Thigpen *et al.* 2010: 702) (Worlikar and Shah 2019: 98). In each view the forward head angle (FHA) and forward shoulder angle (FSA) was measured. The FHA was measured using the craniovertebral angle and the FSA was measured using the acromiovertebral angle. The photos were then loaded onto the PPS8 software which worked out the acromiovertebral and craniovertebral angles.

3.8.3.1) Acromiovertebral angle

This is the measurement used to determine the carrying angle of the shoulder in the sagittal plane when assessed from a lateral viewpoint. Thigpen *et al.* (2010: 702) defined the acromiovertebral angle as the angle formed by the intersection of a vertical line passing through the C7 spinous process and a straight line passing through the acromion and the C7 spinous process. They went on to define an ideal acromiovertebral angle as 22^{o} in the anterior direction and defined a forward shoulder posture as an acromiovertebral angle greater than or equal to 52^{o} in the anterior direction.

3.8.3.2) Craniovertebral angle

This is the measurement used to determine the angle of head carriage in the sagittal plane when assessed from the lateral viewpoint. Thigpen *et al.* (2010: 702) defined the craniovertebral angle as the angle formed by the intersection of a vertical line through the C7 spinous process and a straight line passing through the tragus of the ear and the C7 spinous process. They went on to define an ideal craniovertebral angle as 36^{o} in the anterior direction and defined a forward head posture as a craniovertebral angle greater than or equal to 46^{o} in the anterior direction.

Following completion of the research procedure the participants were thanked and asked to leave. All data collected will be recorded and stored in the patients file at the DUT chiropractic day clinic for a period of 5 years, following which the data will be shredded.

Figure 3.12: Measurement of Acromiovertebral Angle (a) and Craniovertebral Angle (b)

a = Location of camera ; x = Location of participant

Figure 3.13: Layout of Room for Posture Photograph

3.9) Data Quantification

For the purpose of this study, the data collected was quantified as follows:

3.9.1) Quantification of Posture Measurements

Head Angle

-Ideal head angle: ≤ 36°

-Mild forward head angle: 37° – 41°

-Moderate forward head angle: 42° – 46°

-Severe forward head angle: >46°

Shoulder angle:

-Ideal shoulder angle: ≤ 22°

-Mild forward shoulder angle: 23° – 37°

-Moderate forward shoulder angle: 38° – 52°

-Severe forward shoulder angle: >52°

3.9.2) Quantification of Range of Motion

Due to the inconsistency in values given in the literature with regards to commonly accepted parameters for normal range of motion, occurring as a result of inconsistent use of anatomical landmarks in goniometry, range of motion was compared between dominant and non-dominant arms in the participants of the current study only, and the results were not compared to the results of other studies. This allowed the comparison between the dominant shoulders, which undergo the full forces of swimming and overhead throwing, and the non-dominant shoulders, which only undergo the forces of swimming, of the participants. In this way, the non-dominant shoulders served as an ideal reference measurement of each motion within the participants as a result of swimming only and it can then be extrapolated whether the forces of overhead throwing result in an increase or decrease of each motion by comparing these measurements with those of the dominant shoulders. All motions were assessed passively.

3.9.3) Quantification of Orthopaedic Tests

Rotator cuff injury was quantified using 5 orthopaedic tests with three possible results. No positive tests indicated that the participant did not have any rotator cuff injury present, less than 3 out of 5 positive tests indicated an impingement syndrome and 3 or more positive tests indicated a tendonitis.

Long head of biceps tendinopathy and glenoid labrum injury were assessed together using two tests to assess for different types of LHBT/labral injury with either test being positive indicating injury to either of these structures.

Glenohumeral instability was quantified using one test with a positive result indicating instability.

3.10) Statistical Analysis

The procedures for this study were broadly broken down into two categories, those assessing for adaptations and those assessing for injury. The adaptation assessment consisted of the posture measurements for forward head angle and forward shoulder angle as well as the range of motion measurements. The injury assessment consisted of orthopaedic testing which was used to diagnose the presence of any of the five common overuse injuries. IBM SPSS version 27 was used to analyse the data.

In order to compare the posture measurements between the dominant and non-dominant shoulders of male water polo players, the statistician used McNemar's chi square tests since posture measurements were categorised as indicated above and the dominant and non-dominant shoulders were paired groups (two measurements per participant) (Esterhuizen 2020).

In order to compare the Range of motion measurements between the dominant and non-dominant shoulders of male water polo players, the statistician used paired t-tests since ROM measurements were treated as continuous measurements and probably followed a normal distribution (Esterhuizen 2020).

In order to compare the presence of injuries between the dominant and non-dominant shoulders of male water polo players, the statistician used McNemar's chi square tests since injuries were recorded as a binary variable (positive or negative) and the dominant and non-dominant shoulders were paired groups (two measurements per participant) (Esterhuizen 2020).

3.11) Ethical Considerations

This study followed the principles of beneficence, non-maleficence, autonomy and justice to ensure that all ethical considerations were maintained.

Autonomy was ensured by giving participants informed consent and allowing them to withdraw from the study at any time (Avasthi *et al.* 2013: 87). Justice was ensured by treating all participants fairly and equally (Avasthi *et al.* 2013: 87). Non-maleficence was maintained as there were no procedures within the study that might have caused harm to participants (Avasthi *et al.* 2013: 87). Beneficence was maintained as the outcomes of the study may have a positive impact on the rate of shoulder overuse injuries amongst water polo players (Avasthi *et al.* 2013: 87).

In order to ensure anonymity, a code was assigned to each participant so that their name was not used and none of their personal details were used in the interpretation and write-up of the data. The sport-specific shoulder regional sheet (Appendix I) used to record the data during the procedure had a space at the top for the participant's name and their unique study ID code. This information was then transcribed onto a separate data collection sheet (Appendix J) which was then sent to the statistician. The statistician's data sheet (Appendix J) only contained the participants study ID codes along with the results of the procedure and no personal information. In order to ensure confidentiality, only the clinic reception staff and the researcher have access to the personal information and codes used which will be stored in the participants file at the Chiropractic Day Clinic for 5 years and will then be shredded.

CHAPTER FOUR
ANALYSIS OF RESULTS

4.1) Introduction

This chapter will discuss the analysis of the data collected and present the results in terms of the stated objectives and aim of the study.

4.2) Statistical Methodology

IBM SPSS version 27 was used for data analysis. A *p* value <0.05 was considered as statistically significant. Dominant and non-dominant side measurements were compared using paired t-tests where the measurements were quantitative and normally distributed. For categorical binary measurements, McNemar's chi square test for paired binary proportions was used, and where there were more than two categories, McNemar-Bowker tests were used (Esterhuizen 2020).

4.3) Demographic Characteristics of Participants

4.3.1) Age

Thirty-three male water polo players were sampled for this study. Their mean age was 25.6 years with a standard deviation of 4.6 years and a range from 20 to 40 years.

age		
N	Valid	33
	Missing	0
Mean		25.64
Std. Deviation		4.554
Minimum		20
Maximum		40

Table 4.1: Ages of participants

4.3.2) Arm Dominance

Most participants were right arm dominant (32, 97%), with only a single participant being left arm dominant (3%).

		Count	Column N %
Arm dominance	Left	1	3.0%
	Right	32	97.0%
	Total	33	100.0%

Table 4.2: Arm dominance of participants

4.4) Data Analysis

The data collected in the study was analysed based on the following objective: To compare the posture measurements, range of motion and injury assessment in the dominant and non-dominant shoulders of male water polo players.

4.4.1) Analysis of Posture Measurements

4.4.1.1) Acromiovertebral angle

There was no significant difference in the dominant vs non-dominant ratings (p=0.513). The table below shows that on the dominant side, most had moderate forward carriage (24, 73%) while on the non-dominant side 63% (21) had moderate forward carriage. When the two sides were cross tabulated, there was mostly agreement between the two sides. Two participants had mild forward carriage on both sides, 19 participants had moderate forward carriage on both sides and 5 had severe forward carriage on both sides. The non-concordant participants were equally distributed between worse on the dominant side and worse on the non-dominant side.

		Acromiovertebral angle non-dominant rating			Total
		Mild forward carriage	Moderate forward carriage	Severe forward carriage	
Acromiovertebral angle dominant rating	Mild forward carriage	2	1	0	3
	Moderate forward carriage	2	19	3	24
	Severe forward carriage	0	1	5	6
Total		4	21	8	33

Table 4.3: Acromiovertebral Angle Ratings

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
McNemar-Bowker Test	1.333	2	0.513
N of Valid Cases	33		

Table 4.4: Chi-Square Test of Acromiovertebral Angle Ratings

4.4.1.2) Craniovertebral angle

There was no significant difference in the dominant vs non dominant ratings (*p*=0.534). The table below shows that, on the dominant side, a moderate amount had severe forward carriage (14, 42%), while on the non-dominant side, the same number had severe forward carriage. When the two sides were cross tabulated, there was partial agreement between the two sides. One participant had ideal carriage on both sides, 4 participants had mild forward carriage on both sides, 2 participants had moderate forward carriage on both sides and 9 had severe forward carriage on both sides. The non-concordant participants were equally distributed between worse on the dominant side and worse on the non-dominant side.

		Craniovertebral angle non-dominant rating				Total
		Ideal carriage	Mild forward carriage	Moderate forward carriage	Severe forward carriage	
Craniovertebral angle dominant rating	Ideal carriage	1	0	0	0	1
	Mild forward carriage	2	4	2	0	8
	Moderate forward carriage	1	2	2	5	10
	Severe forward carriage	0	1	4	9	14
Total		4	7	8	14	33

Table 4.5: Craniovertebral Angle Ratings

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
McNemar-Bowker Test	4.111	5	0.534
N of Valid Cases	33		

Table 4.6: Chi-Square Test of Craniovertebral Angle Ratings

4.4.2) Analysis of Range of Motion Measurements

There was no difference between the dominant and non-dominant internal and external rotation measurements. There was a borderline statistically significant (p=0.05) difference between the dominant and non-dominant horizontal adduction measurements with the non-dominant measurement being higher.

	Mean	N	Std. Deviation	Std. Error Mean	p-value
Internal rotation dominant passive	105.15	33	17.209	2.996	0.356
Internal rotation non dominant passive	102.76	33	15.054	2.621	
External rotation dominant passive	85.36	33	11.244	1.957	0.968
External rotation non dominant passive	85.45	33	11.924	2.076	
Horizontal adduction dominant passive	126.52	33	10.707	1.864	0.050
Horizontal adduction non dominant passive	129.70	33	11.016	1.918	

Table 4.7: Range of motion Results

4.4.3) Analysis of Orthopaedic Test Results

4.4.3.1) Empty Can Test

A total of 16 participants (48%) yielded positive results for the empty can test, with 2 participants (6%) being positive bilaterally, 2 participants (6%) positive in the non-dominant side only, and 14 participants (42%) being positive in the dominant side only. There was a significant difference between dominant and non-dominant empty can test results (*p*=0.013). There was more discordance in the upper right cell (positive in the dominant and negative in the non-dominant) than in the lower left cell. This means that the dominant side was more likely to be positive on this test than the non-dominant side.

		Empty can test non-dominant		Total
		Positive	Negative	
Empty can test dominant	Positive	2	12	14
	Negative	2	17	19
Total		4	29	33

Table 4.8: Empty Can Test results

Chi-Square Tests		
	Value	Exact Sig. (2-sided)
McNemar Test		0.013[a]
N of Valid Cases	33	
a. Binomial distribution used.		

Table 4.9: Chi-Square Test of Empty Can Test Results

4.4.3.2) Painful Arc Test

The painful arc test was negative in all but one participant on the dominant side. All non-dominant sides were negative. No statistical test was possible here.

		Painful arc test non-dominant	Total
		Negative	
Painful arc test dominant	Positive	1	1
	Negative	32	32
Total		33	33

Table 4.10: Painful Arc Test Results

4.4.3.3) Hawkins-Kennedy Test

A total of 18 participants (55%) tested positive for the Hawkins-Kennedy test, with 2 participants (6%) positive bilaterally, 10 participants (30%) positive on the non-dominant side only, and 8 participants (24%) positive on the dominant side only. There was no significant difference between dominant and non-dominant sides for this test (p=0.454).

		Hawkins-Kennedy test non-dominant		Total
		Positive	Negative	
Hawkins-Kennedy test dominant	Positive	2	6	8
	Negative	10	15	25
Total		12	21	33

Table 4.11: Hawkins-Kennedy Test Results

Chi-Square Tests		
	Value	Exact Sig. (2-sided)
McNemar Test		0.454[a]
N of Valid Cases	33	
a. Binomial distribution used.		

Table 4.12: Chi-Square Test of Hawkins-Kennedy Test Results

4.4.3.4) External Rotation Resistance Test

This test was negative in all but two participants in the dominant side. All non-dominant sides were negative. No statistical test was possible here.

		External rotation resistance test non-dominant	Total
		Negative	
External rotation resistance test dominant	Positive	2	2
	Negative	31	31
Total		33	33

Table 4.13: External Rotation Resistance Test Results

4.4.3.5) Neer Test

A total of 8 participants (24%) tested positive for this test, with 4 participants (12%) testing positive in the non-dominant side only, 3 participants (9%) testing positive in the dominant side only, and only 1 participant (3%) testing positive bilaterally. There was no difference in the dominant and non-dominant sides for this test (p=1.00). There were almost equal numbers who were positive on dominant yet negative on non-dominant and vice versa.

		Neer test non-dominant		Total
		Positive	Negative	
Neer test dominant	Positive	1	3	4
	Negative	4	25	29
Total		5	28	33

Table 4.14: Neer Test Results

Chi-Square Tests		
	Value	Exact Sig. (2-sided)
McNemar Test		1.000[a]
N of Valid Cases	33	
a. Binomial distribution used.		

Table 4.15: Chi-Square Test of Neer Test Results

4.4.3.6) Yergasson's Test

In this test all participants tested negative on the dominant side and only one participant tested positive on the non-dominant side. No statistical tests were possible.

		Yergasson's test non-dominant		Total
		Positive	Negative	
Yergasson's test dominant	Negative	1	32	33
Total		1	32	33

Table 4.16: Yergasson's Test Results

4.4.3.7) Biceps Load Test II

A total of 11 participants (33%) tested positive for this test, with 6 participants (18%) positive bilaterally, 3 participants (9%) positive on the non-dominant side only, and 2 participants (6%) positive on the dominant side only. There was no difference in the dominant and non-dominant sides for this test (p=1.00). There were almost equal numbers who were positive on dominant yet negative on non-dominant and vice versa.

		Biceps load test non-dominant		Total
		Positive	Negative	
Biceps load test dominant	Positive	6	2	8
	Negative	3	22	25
Total		9	24	33

Table 4.17: Biceps Load Test II Results

Chi-Square Tests		
	Value	Exact Sig. (2-sided)
McNemar Test		1.000[a]
N of Valid Cases	33	
a. Binomial distribution used.		

Table 4.18: Chi-Square Test of Biceps Load Test II Results

4.4.3.8) Apprehension-Relocation-Surprise Test

A total of 10 participants (30%) tested positive for this test, with 2 participants (6%) positive bilaterally, 5 participants (15%) positive on the non-dominant side only, and 3 participants (9%) positive on the dominant side only. There was no significant difference in the dominant and non-dominant sides for this test (p=0.727). There were almost equal numbers who were positive on dominant yet negative on non-dominant and vice versa.

		Apprehension-relocation-surprise test non-dominant		Total
		Positive	Negative	
Apprehension-relocation-surprise test dominant	Positive	2	5	7
	Negative	3	23	26
Total		5	28	33

Table 4.19: Apprehension-Relocation-Surprise Test Results

Chi-Square Tests		
	Value	Exact Sig. (2-sided)
McNemar Test		0.727[a]
N of Valid Cases	33	
a. Binomial distribution used.		

Table 4.20: Chi-Square Test of Apprehension-Relocation-Surprise Test Results

4.4.4) Anterior glenohumeral Instability

Anterior glenohumeral instability was assessed using one test, the apprehension-relocation surprise test, with a positive result for this test indicating instability. As a result, the presence of anterior glenohumeral instability in the participants of the current study correlates directly to the results of the apprehension-relocation-surprise test, with a total of 10 participants (30%) testing positive for instability. 2 participants (6%) were positive bilaterally, 5 participants (15%) were positive on the non-dominant side only, and 3 participants (9%) were positive on the dominant side only. There was no significant difference in the dominant and non-dominant sides for instability (p=0.727).

		Anterior glenohumeral instability non-dominant		Total
		Positive	Negative	
Anterior glenohumeral instability dominant	Positive	2	5	7
	Negative	3	23	26
Total		5	28	33

Table 4.21: Anterior Glenohumeral Instability Results

Chi-Square Tests		
	Value	Exact Sig. (2-sided)
McNemar Test		0.727[a]
N of Valid Cases	33	
a. Binomial distribution used.		

Table 4.22: Chi-Square Test of Anterior Glenohumeral Instability Results

4.4.5) Rotator Cuff Injuries

Participants were classified as having impingement syndrome if one or two of the rotator cuff tests were positive, and tendonitis if three or more were positive. Those with no positive tests were classified as negative for rotator cuff injuries. A total of 23 participants (70%) tested positive for rotator cuff injury. Bilaterally, 10 participants (30%) tested positive for impingement syndrome and 10 participants (30%) tested negative for any rotator cuff injury. On the dominant side 2 (6%) had tendonitis, 16 (49%) had impingement syndrome, and the remainder (15, 45%) were negative, while on the non-dominant side 15 (45%) had impingement and the remainder (18, 55%) were negative. There was thus no test possible to compare the two sides with regards to rotator cuff injuries. No statistical test was possible due to the unbalanced table (3 by 2).

		Rotator cuff injury non-dominant		Total
		Negative	Impingement syndrome	
Rotator cuff injury dominant	Negative	10	5	15
	Impingement syndrome	6	10	16
	Tendonitis	2	0	2
Total		18	15	33

Table 4.23: Rotator Cuff Injury Results

4.4.6) Glenoid Labrum and Long Head of Biceps Tendon Injury

Participants were classified as having labrum or LHBT injury if either one of the two tests were positive. A total of 12 participants (36%) tested positive for glenoid labrum injury, with 6 participants (18%) being positive bilaterally. 2 participants (6%) tested positive in the dominant side only and 4 participants (12%) tested positive on the non-dominant side only. There was no difference in the dominant and non-dominant sides for this test (*p*=0.687). There were almost equal numbers who were positive on dominant yet negative on non-dominant and vice versa.

		Glenoid labrum non-dominant injury		Total
		Negative	Positive	
Glenoid labrum dominant injury	Negative	21	4	25
	Positive	2	6	8
Total		23	10	33

Table 4.24: Glenoid Labrum and LHBT Injury Results

Chi-Square Tests		
	Value	Exact Sig. (2-sided)
McNemar Test		0.687[a]
N of Valid Cases	33	
a. Binomial distribution used.		

Table 4.25: Chi-Square Test of Glenoid Labrum and LHBT Injury Results

4.5) Conclusion

There were not many differences between the dominant and non-dominant sides of water polo players in terms of the measured variables. Horizontal adduction measurements showed greater values on the non-dominant side, and the empty can test showed more positivity on the dominant side.

CHAPTER FIVE
DISCUSSION OF RESULTS

5.1) Introduction

This chapter critically discusses the results of the study in terms of the stated objectives and with regard to the current literature surrounding the study.

5.2) Discussion of Demographic Data

5.2.1) Sex

Differences in the sex of the participants of a research study plays an important role in the interpretation and validity of the results obtained from that study, especially when investigating internal mechanisms of disease or injury. According to Clayton (2018), there are obvious differences in the manifestation of diseases between males and females, as well as differences in their response to treatments. As a result, the findings obtained from a study that utilises both male and female participants may represent two different mechanisms of disease/pathology, with each one unique to a specific sex, and, therefore, the findings may not be directly applicable to everyone. In order to account for this and to ensure reproducibility of the results, Clayton (2018) recommends conducting individual studies on each sex so that the number of variables in the sample can be minimised and homogeneity can be ensured. Based on this, the current study utilised an all-male sample (n=33) in order to ensure homogeneity and reproducibility.

5.2.2) Age

Osteoarthritis and other degenerative disorders are important factors to consider when conducting a research study, particularly one that is looking into overuse injuries in an area that is extremely prone to degeneration. According to the American Academy of Orthopaedic Surgeons (2013), osteoarthritis and other degenerative processes involving the glenohumeral joint usually affect people over the age of 50. In light of this, and in order to ensure reproducibility of the results, the current study limited the age of the sample population to those between the ages of 18-45 years old. However, the actual ages of the participants of the current study ranged from 20-40 years of age, with only one participant being over the age of 35 years old. As a result, the ages of the participants fell well within the parameters for age in this study, minimising the influence of age-related degeneration.

5.2.3) Arm Dominance

The effect of arm dominance in the current study is minimal as this study compares the dominant arm to the non-dominant arm and, therefore, differences between the two sides are expected. By comparing the dominant arm to the non-dominant arm in terms of the stated objectives, it was possible to observe the baseline, bilateral effects of swimming that would be occurring in both shoulders by assessing the non-dominant shoulders and then comparing these to the effects of overhead throwing that would be occurring exclusively in the dominant shoulders of the participants. However, in order to account for differences in arm dominance between participants and to ensure accurate results, it was necessary to record each participants preference for arm dominance. Of all the participants (n=33), only a single participant (3%) was left-arm dominant, with the remaining 32 participants (97%) being right-arm dominant.

5.3) Discussion of Posture Results

The results of this study in terms of the head and shoulder posture measurements of water polo players agree with those of other studies that have found that water polo players characteristically develop a forward head posture with rounded shoulders (Gradidge *et al.* 2014; Aginsky, Tracey and Neophytou 2016). FHPRS is very common amongst water polo players, with 73% of the participants in this study displaying a bilateral forward shoulder position ranging from moderate to severe, and 45% of participants displaying a bilateral forward head posture ranging from mild to severe. In addition, the results of this study found that 88% of participants displayed some degree of excessive forward head posture and all of the participants displayed some degree of excessive forward shoulder posture, which agrees with the study by Aginsky, Tracey and Neophytou (2016) that found that more than 70% of the players they studied had a forward head posture and all of them displayed some degree of rounded shoulders.

Most of the participants of this study experienced these postural abnormalities bilaterally, suggesting that this change in posture is most likely related to the bilaterally equal forces of swimming. However, the exact causes of gradual changes in posture are hard to pinpoint and there could be several factors from the participants daily lives that may influence their head and shoulder posture, such as occupation, hobbies, and other sports that the participants may play recreationally. One of the most common causes of FHPRS in recent times is the syndrome that has been coined “Text Neck”. Text neck syndrome is the name given to the condition of neck and upper thoracic spine pain that occurs as a result of individuals spending prolonged periods of time everyday looking down at screens on smartphones, laptops, and computers that are usually below eye-level (Neupane, Ali and Mathew 2017). Spending such long periods of time looking down towards screens places the cervical spine in a constant state of forward flexion that subsequently alters the normal biomechanics of the neck and shoulders leading to a forward head posture with rounded shoulders (Neupane, Ali and Mathew 2017). According to Neupane (2017), 79% of the population between the ages of 18-44 have been found to carry their smartphones with them at all times. This statistic could play a large part in explaining the high frequency of FHPRS found in the participants of this study as all of the study participants fell within the age range of 20-40 years-of-age. Seen in this light, it is very possible that the posture of most of the participants was influenced not only by the repetitive bilateral forces of swimming, but possibly also by the constant, gradual forces generated with text neck syndrome.

The abnormal posture of these players lays the grounds for the potential development of unilateral injuries in their dominant shoulders that would occur as a result of the traumatic forces of overhead throwing occurring in a biomechanically unstable joint complex, characterised by a decreased ability of the scapula to protract or rotate upwards, leading to an inability of the humeral head to clear the acromion during elevation of the humerus when performing the overhead throwing motion (Pollard and Croker 1999; Borsa, Laudner and Sauers 2008; Hibberd *et al.* 2016).

5.4) Discussion of Range of Motion Results

The range of motion results for this study were somewhat as expected. According to several authors, water polo players commonly present with a unique set of shoulder mobility adaptations that is described as an ERG in the dominant shoulder when compared to the non-dominant shoulder and a bilaterally symmetrical GIRD, along with a loss of horizontal adduction in the dominant shoulder when compared to the non-dominant shoulder (Wang and Cochrane 2001; Borsa, Laudner and Sauers 2008). These mobility adaptations have been confirmed by the current study to a certain degree, with this study finding a significant difference in horizontal adduction measurements between sides, as well as a bilaterally symmetrical range of internal rotation; the only range of motion result from this study that does not concur with the findings of Keller *et al.* (2018), Weber et al (2014), Borsa, Laudner and Sauers (2008), and others, with regards to the mobility adaptations in the shoulders of overhead throwers, is the lack of a significant difference in the external rotation ROM measurements between sides.

It has been suggested that, due to the repetitive nature of the bilaterally equal forces of swimming, swimmers are prone to the development of a GIRD in both shoulders that results in a bilateral decrease in internal rotation ROM, resulting in a gradual, bilaterally equal decrease in internal rotation ROM (Pollard and Croker 1999; Borsa, Laudner and Sauers 2008; Hibberd *et al.* 2016). This gradual, bilaterally equal loss of glenohumeral internal rotation ROM could potentially explain the lack of a significant difference in the internal rotation ROM measurements recorded in this study as all of the participants would have experienced a bilateral loss of internal rotation ROM as a result of their many years of swimming training.

The lack of a significant difference in the external rotation ROM measurements in the current study is not as expected as the literature suggests that there should be an ERG in the dominant shoulder when compared to the non-dominant shoulder in overhead throwers (Borsa, Laudner and Sauers 2008; Weber *et al.* 2014; Keller *et al.* 2018). The ERG in the dominant shoulders of overhead throwers is suggested to occur as a result of the acquired hyper-laxity theory in which a glenohumeral rotational backshift occurs in the dominant shoulders of overhead throwers as a result of the extreme abduction and external rotation at the end of the backswing phase of throwing, leading to forceful stretching of the anterior capsuloligamentous structures and a subsequent increase in the amount of external rotation possible (Borsa, Laudner and Sauers 2008; Keller *et al.* 2018; Lin, Wong and Kazam 2018). However, the lack of an identifiable increase in external rotation ROM in the dominant shoulders of the participants in the current study confirms Borsa, Laudner and Sauers (2008) view that there is little evidence to support this theory. This view is further supported by the lack of a significant difference between sides in the results from this study for the apprehension-relocation-surprise test that assesses for any stretching or attenuation of the anterior glenohumeral capsuloligamentous structures. All of this suggests that there is either no change in the external rotation ROM on the dominant side or that there is a bilaterally symmetrical change in this ROM which would suggest that it is occurring as a result of the bilateral forces of swimming as opposed to the unilateral forces of overhead throwing.

The only significant ROM result identified in this study was the significant difference in horizontal adduction measurements between sides, as predicted by the literature (Borsa, Laudner and Sauers 2008; Wilk *et al.* 2011; Weber *et al.* 2014). This horizontal adduction deficit, defined by a loss of horizontal adduction in the dominant shoulder when compared to the non-dominant shoulder, is extremely important in the shoulders of overhead throwers and could potentially explain the prevalence for certain common injuries in the dominant shoulders of overhead throwers. Though the exact cause of this horizontal adduction deficit is not yet known, the results of the current study suggest that it may be explained by the posterior shoulder immobility theory, in which the repetitive microtrauma experienced during overhead throwing leads to contracture of the posterior shoulder structures with resultant loss of internal rotation and horizontal adduction (Borsa, Laudner and Sauers 2008; Takenaga *et al.* 2015). Seen in this light, progressive tightening of the posterior capsule as a response to forceful stretching during the follow-through phase of overhead throwing, or progressive tightening of the posterior rotator cuff musculature as a result of repetitive eccentric overload during arm deceleration following ball release, leads to contracture of the posterior shoulder structures in the dominant shoulder and the resultant horizontal adduction deficit (Borsa, Laudner and Sauers 2008; Wilk *et al.* 2011; Takenaga *et al.* 2015).

5.5) Discussion of Shoulder Overuse Injury Test Results

The shoulder orthopaedic tests used in this study were selected specifically to assess for the most common injuries reported amongst water polo players according to Franic, Ivkovic and Rudic (2007), Galluccio *et al.* (2017), and Mountjoy, Miller and Junge (2019), which included rotator cuff tendonitis, subacromial impingement, glenohumeral instability, long head of the biceps tendinopathy, and glenoid labrum injury. Based on this, injuries were grouped into 3 groups: Rotator cuff injury (consisting of subacromial impingement and rotator cuff tendonitis); glenoid labrum injury (consisting of labral lesions and LHBT tendinopathy); and anterior glenohumeral instability.

Though several tests reported moderate levels of positivity in either shoulder (55% positive for Hawkins-Kennedy; 33% positive for Biceps load II test; 30% positive for Apprehension-relocation-surprise test; 24% for Neer test), the lack of a significant difference between sides for these tests either suggests that the injuries that these tests assess for are more likely the result of the bilateral forces of swimming than the unilateral forces of overhead throwing, or that the forces of swimming and overhead throwing are both equally as likely to result in these specific injuries. Regardless of the exact mechanism of development, the bilaterally equal distribution of these injuries, coupled with the lack of a significant difference in terms of posture measurements and, to a large extent, the range of motion measurements between sides, indicates that the mechanism of development of these specific shoulder overuse injuries in water polo players is at the very least extremely similar to the development of these same injuries in swimmers, if not exactly the same.

5.5.1) Anterior Glenohumeral Instability

Anterior glenohumeral instability occurring in the shoulders of overhead throwers is thought to be the result of the acquired hyper-laxity theory of mobility adaptation in the shoulders of these athletes (Gelber, Soloff and Schickendantz 2018). According to this theory, stretching of the anterior glenohumeral capsuloligamentous structures with the subsequent onset of anterior glenohumeral instability in the dominant shoulder leads to an external rotation gain in the throwing shoulders of these athletes (Borsa, Laudner and Sauers 2008; Gelber, Soloff and Schickendantz 2018; Miller *et al.* 2018). However, the results of the apprehension-relocation-surprise test suggest that this theory is unlikely as there were no significant differences in the number of participants with anterior instability in the dominant shoulder when compared to the non-dominant shoulder. In fact, the results of the apprehension-relocation-surprise test support the results of the range of motion assessment that found that there were no significant differences in the external rotation range of motion measurements between the two shoulders. This data agrees with the conclusions of Sein et al. (2010) that there is little evidence of the acquired hyper-laxity theory actually occurring in the shoulders of overhead athletes.

5.5.2) Glenoid Labrum and Long Head of Biceps Tendon Injury

The results of this study regarding the incidence of glenoid labrum and LHBT injury mostly agrees with the current literature and suggests that there is an equal distribution in the frequency of these injuries between the dominant and non-dominant shoulders in water polo players. Galluccio et al. (2017) found relatively low, but still significant, incidences of these injuries in elite and sub-elite level water polo players, with a total incidence of 26% for LHBT tendinopathy in their study (9.52% positive bilaterally, 16.67% positive on the dominant side only) and a total incidence of 7% for labral lesions in their study (4.76% positive on the dominant side only and 2.38% positive on the non-dominant side only). This is mostly in accordance with the findings of the current study that found a total incidence of 36% for combined glenoid labrum and LHBT injury, with 18% positive bilaterally and 6% positive on the dominant side only. The only discrepancy between the findings of the current study and those of Galluccio et al (2017) is that the current study found that 12% of the participants were positive for glenoid labrum or LHBT injury on the non-dominant side only and the study by Galluccio et al. (2017) identified no incidences of LHBT injury in the non-dominant shoulders of their participants and only 2.38% of their participants were positive for labral lesions on the non-dominant side only. However, Galluccio et al. (2017) reported a bilateral incidence of 9.52% for LHBT injury which still suggests that there is an underlying mechanism of injury that is affecting both the dominant and non-dominant shoulders with relatively equal frequency.

The equal distribution of positive results for the Biceps Load Test II between the dominant and non-dominant shoulders of the participants in the current study suggests that, while there may be some glenoid labrum or LHBT injury present, they are not exclusively the result of the extreme abduction and external rotation of the glenohumeral joint during the backswing phase of overhead throwing and may occur through similar processes to those that occur in the shoulders of swimmers. This is further supported by the lack of an external rotation gain through acquired hyper-laxity in either shoulder of the participants of the current study that would potentially place additional stress on the LHBT and glenoid labrum when in this position at the end point of the backswing phase of overhead throwing.

Though the results of Yergassons' test were inconclusive due to a lack of data, the loss of horizontal adduction in the dominant shoulders of the participants of this study supports the theory of posterior shoulder immobility occurring in the dominant shoulders of water polo players. This theory would agree with Erickson et al. (2016) who suggested that the extreme forces experienced by the LHBT and, subsequently, the glenoid labrum during the deceleration phases of overhead throwing could lead to LHBT tendinopathy and SLAP lesions. This would suggest that the follow-through and deceleration phases of overhead throwing are extremely traumatic to the structures of the glenohumeral joint and may directly result in a loss of horizontal adduction and an increased risk of developing glenoid labrum and LHBT injury.

Therefore, the results of the Biceps Load test II for SLAP lesions and Yergasson's test for biceps tendinopathy support the posterior shoulder immobility theory of mobility adaptation in the dominant shoulders of water polo players, and, subsequently, the deceleration theory of glenoid labrum and LHBT injury, over the acquired hyper-laxity theory of mobility adaptation, which would be linked to the peel-back mechanism of glenoid labrum and LHBT injury.

5.5.3) Rotator Cuff Injury

Despite the fact that the results of the Painful Arc and External Rotation Resistance tests were inconclusive due to a lack of data, the method of assessing rotator cuff injury using 5 different tests, as suggested by Michener *et al.* (2009), Hegedus *et al.* (2012) and Itoi (2013), proved extremely useful and some interesting data was recorded with the other tests.

The Hawkins-Kennedy test and the Neer test did not reveal a significant difference between sides. However, the bilateral effects of Swimmers' shoulder are very common amongst swimmers and, by extension, water polo players (Almeida *et al.* 2011; Klein *et al.* 2014; De Martino and Rodeo 2018). The high rates of positivity for the Hawkins-Kennedy test (55% of participants) confirms that rotator cuff pathology is extremely common amongst these athletes; however, the lack of prevalence for the dominant side to be positive more than the non-dominant side indicates that this test is most likely identifying rotator cuff injury that is occurring as a result of the bilateral forces of swimming as opposed to injury occurring exclusively as a result of the unilateral forces of overhead throwing.

The only test for rotator cuff injury that yielded a significant difference between sides was the empty can test for supraspinatus tendinopathy. In this test, there was a clear prevalence for participants to test positive on the dominant side when compared to the non-dominant side. This indicates that supraspinatus tendinopathy is much more frequent in the dominant shoulders of water polo players when compared to the non-dominant shoulders and is most likely occurring as a direct result of the unilateral forces of overhead throwing. This pattern of a moderate level of bilateral rotator cuff injury (indicated by the bilaterally equal distribution of positive results for the Hawkins-Kennedy and Neer tests) coupled with a significantly higher level of unilateral supraspinatus-specific rotator cuff injury in the dominant shoulder when compared to the non-dominant shoulder (indicated by the results of the empty can test) is common amongst water polo players as a result of the bilateral effects of swimming combined with the unilateral effects of overhead throwing (Borsa, Laudner and Sauers 2008; Klein *et al.* 2014; Galluccio *et al.* 2017).

When the results of the empty can test are interpreted in the light of the combined posture, injury, and range of motion results, an interesting clinical picture of the adaptations in the dominant shoulders of water polo players begins to develop.

5.6) Conclusion

The results of the current study indicate that water polo players present with a unique set of shoulder mobility adaptations that somewhat agrees with previous descriptions in the literature, but with a few key differences. In general, the participants of this study presented with the following adaptations: a bilaterally equal forward head posture with rounded shoulders, coupled with a loss of horizontal adduction in the dominant shoulders and an equal range of internal and external glenohumeral rotation bilaterally. In terms of injury, there was a bilaterally equal distribution of rotator cuff injury, labral injury, and anterior glenohumeral instability, with the only significant injury result being a higher prevalence of supraspinatus-specific rotator cuff injury in the dominant shoulders. Based on this, the process of mobility adaptation and subsequent injury in the dominant shoulders of water polo players can be better understood.

The results from this study suggest that water polo players are prone to the development of a bilaterally equal forward head posture with rounded shoulders, much like swimmers. This posture inevitably results in a decreased ability of the scapula to protract or rotate upwards, leading to an inability of the humeral head to clear the acromion during elevation of the humerus when performing the overhead throwing motion, resulting in compression of the supraspinatus tendon near its insertion onto the humerus (Pollard and Croker 1999; Borsa, Laudner and Sauers 2008; Hibberd *et al.* 2016). Additionally, it has been found that a forward shoulder posture negatively correlates with subacromial space distance meaning that, as forward shoulder posture increases, subacromial space decreases (Hibberd *et al.* 2016); this greatly increases the rate of contact between the supraspinatus tendon and the coracoacromial arch. However, these mechanisms of injury would likely occur at equal rates in both shoulders of water polo players as they are occurring as a result of the bilaterally equal effects of a FHPRS - this is supported by the bilateral distribution of generalised rotator cuff injury in the current study.

In addition to this, the traumatic forces experienced in the dominant shoulders by the posterior rotator cuff musculature and the posterior glenohumeral joint capsuloligamentous structures during the follow-through and deceleration phases of overhead throwing place enormous strain on these structures, with the eventual development of posterior shoulder immobility, either as a result of progressive tightening of the posterior capsule as a response to forceful stretching during follow-through, or due to progressive tightening of the posterior rotator cuff musculature as a result of repetitive eccentric overload during arm deceleration following ball release (Borsa, Laudner and Sauers 2008; Wilk *et al.* 2011; Lin, Wong and Kazam 2018). This posterior shoulder immobility in the dominant shoulders of these athletes would result in a decreased range of horizontal adduction, as demonstrated by this study.

The onset of low-grade inflammation in the posterior cuff musculature, particularly the supraspinatus, as a result of these combined factors would result in localised intra-muscular oedema with a further decrease in the subacromial space distance (Davis 2014; Galluccio *et al.* 2017; De Martino and Rodeo 2018), as suggested by Sein et al. (2010) when describing a similar process bilaterally in swimmers. However, the use of the dominant arm for throwing in water polo players would place a lot more strain on the supraspinatus muscle and tendon compared to the forces of swimming and would, therefore, result in a much higher frequency of supraspinatus-specific rotator cuff injury in the dominant shoulders of water polo players when compared to the non-dominant shoulders, as indicated by the results of the empty can test in this study.

In addition, the follow-through and deceleration phases of overhead throwing may also be traumatic to the LHBT and the glenoid labrum, with the deceleration theory hypothesising that the forces placed on these structures in an effort to slow down the throwing arm following ball release may eventually lead to detachment of the biceps anchor from the glenoid rim, resulting in a SLAP lesion (Erickson *et al.* 2016). It may also be hypothesised that the loss of horizontal adduction in the dominant shoulders of these athletes decreases the ability of the posterior joint structures to absorb force transmitted through them as the throwing arm crosses the body following ball release. This may inevitably lead to an increased reliance on the LHBT and glenoid labrum to absorb this extra force, potentially increasing the rate of injury to these structures in the dominant shoulders of overhead throwers, though there was no evidence in this study for the dominant side to have a higher rate of glenoid labrum or LHBT injury.

All of this suggests that the follow-through and deceleration phases of overhead throwing are the most traumatic phases of the overhead throwing motion, as opposed to the commonly accepted view that the extreme abduction and external rotation at the end point of the backswing phase of overhead throwing leads to gradual stretching of the anterior capsuloligamentous structures with the subsequent onset of anterior glenohumeral instability and a glenohumeral rotational backshift. This highlights the importance of implementing a targeted training programme in water polo players that aims at maintaining a normal head and shoulder posture while also strengthening the posterior cuff musculature and avoiding overuse of these structures.

CHAPTER SIX
CONCLUSION

6.1) Introduction

This chapter will conclude the study with regards to the aim of the study and the stated objectives, as well as discussing any limitations to the study and recommendations for future studies.

6.2) Aim of Study

The aim of this study was to compare the dominant and non-dominant shoulder complexes of male water polo players in terms of posture, range of motion and current overuse injuries in order to develop an understanding of the combined effects of swimming and overhead throwing on the shoulders of water polo players. The results of this study confirmed the alternate hypothesis that stated that there will be a statistically significant difference ($p<0.05$) in the sport-specific measurements for posture, range of motion and overuse injuries between the dominant and non-dominant shoulders of the participants. This is evident in the significant differences identified between sides for the empty can test for supraspinatus injury ($p=0.013$) and the horizontal adduction range of motion measurements ($p=0.050$). This data suggests that the mechanism of development of shoulder overuse injuries in water polo players is specific to the sport and involves a unique combination of the mobility adaptations and biomechanical changes found in swimmers with those found in overhead throwing athletes. Subsequently, as a result of the reliance on the dominant arm for most of the overhead throwing, the process of overuse injury development in the dominant shoulder is significantly different to that in the non-dominant shoulder of water polo players.

6.3) Objective 1: Measurement of Head and Shoulder Posture

The results of this study suggest that a forward head posture with rounded shoulders is extremely common amongst water polo players, most likely as a result of the continuous forces of swimming combined with the effects of everyday activities that promote this posture. The study identified some degree of excessive forward shoulder posture in every single participant of the study and found that 88% of participants had some degree of excessive forward head posture. It can be assumed that this posture sets up a biomechanically unstable shoulder complex that makes water polo players a lot more likely to develop some degree of generalised shoulder overuse injury in either shoulder.

6.4) Objective 2: Measurement of Shoulder Range of Motion

The results of this study indicate that there is no external rotation gain in either shoulder of water polo players. In addition, the results suggest that there is either no glenohumeral internal rotation deficit in either shoulder of water polo players or that, if there is a GIRD present in the shoulders of these athletes, it is occurring equally in both shoulders. The study also identified a significant decrease in the horizontal adduction ROM in the dominant shoulders of water polo players when compared to the non-dominant shoulders. These mobility adaptations are explained by the posterior shoulder immobility theory that posits that the ballistic forces experienced by the posterior rotator cuff musculature and the posterior glenohumeral joint capsuloligamentous structures in the dominant shoulder during the deceleration and follow-through phases of overhead throwing make these structures a lot more prone to damage that inevitably results in posterior shoulder immobility with an associated loss in horizontal adduction.

6.5) Objective 3: Shoulder Overuse Injuries

The results of this study confirmed that generalised rotator cuff injury, LHBT and labral injury, and anterior glenohumeral instability are extremely common amongst water polo players and mostly occur with equal frequency in the dominant and non-dominant shoulders. In addition, the study identified a significantly higher frequency of supraspinatus-specific rotator cuff injury in the dominant shoulders of the participants. This suggests that the bilaterally equal forces of swimming are most likely to blame for the presence of anterior glenohumeral instability, LHBT and labral injury, and generalised rotator cuff injury. However, the higher frequency of supraspinatus-specific rotator cuff injury in the dominant shoulders suggests that this type of injury is most likely caused exclusively by the forces of overhead throwing.

6.6) Objective 4: Interpretation of Combined Measurements

When the specific patterns of injury that were identified in the participants are seen in the light of the postural and mobility adaptations that occur in these athletes, it becomes apparent that the repetitive, bilateral forces of swimming result in abnormal biomechanics in both shoulders that makes these athletes more prone to developing the specific group of shoulder overuse injuries commonly identified in swimmers. However, the unilateral, ballistic forces of overhead throwing that occur exclusively in the dominant shoulders of these athletes then triggers an independent mechanism of injury in the dominant shoulders that involves posterior shoulder immobility with a loss in horizontal adduction and a resultant decrease in the ability of the shoulder to control the forces generated during the follow-through and deceleration phases of throwing, leading to extra strain placed on the posterior cuff musculature to dissipate this force and the subsequent development of supraspinatus-specific rotator cuff injury.

6.7) Limitations

1) Several of the injury tests were inconclusive due to a lack of positive findings. The relatively small sample size (n=33) may be responsible for this and might have resulted in several of these less common injuries being under reported.

2) The study only used asymptomatic participants and, therefore, the results may not be directly applicable to symptomatic individuals.

3) The recruitment of participants for this study was based on current level of play and did not take amount/duration of training or years of play into account. These factors may have a significant impact on the biomechanical adaptations as well as the rates and types of injury experienced.

4) The covid-19 pandemic that was occurring concomitantly to this study meant that a lot of the participants who took part in the study were not actively training or playing games at the time of data collection and might not have done so for a several months prior to the data collection phase.

5) It should be acknowledged that the use of manual goniometry for the measurement of joint range of motion may not be the most precise method available to assess these measurements.

6) The study only utilised male participants in order to ensure homogeneity within the sample population. This means that the results of this study may not be directly applicable to female players.

6.8) Recommendations

1) Future studies should utilise a larger sample size in order to ensure better accuracy of the results and to make sure that there is no under-reporting of less common injuries.

2) Future studies should attempt to utilise a longitudinal design to follow young players in order to monitor the changes in posture and range of motion over years, or to monitor them in players over a single season in order to see the effects of in-season training and games on these outcomes.

3) Future studies should consider the use of players with water polo related symptomatic injury in order to get a better understanding of the injury mechanisms in these players and how they directly relate to posture and range of motion measures.

4) Future studies should consider using a more accurate device to measure joint range of motion, such as a digital goniometer.

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APPENDICES

APPENDIX A: Letter of Information

Title of the Research Study:
An analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players

Principal Investigator/s/researcher:
Conor Gibb (B.Tech Chiropractic)

Co-Investigator/s/supervisor/s:
Dr Grant Matkovich (M.Tech Chiropractic)

Brief Introduction and Purpose of the Study:
The study is a musculoskeletal assessment of both the dominant and non-dominant shoulder complexes of male first division waterpolo players in order to investigate the combined effects of swimming and overhead throwing on the shoulder complexes of these athletes. This will allow the me to develop a better understanding of the mechanism of shoulder overuse injury development in waterpolo players and potentially identify measures which can be taken to decrease the incidence of these types of injuries. The study will consist of approximately 33 male first division waterpolo players who will undergo a shoulder digital posture exam and a shoulder-complex physical exam consisting of range of motion and orthopaedic testing.

Outline of the Procedures:
The study will be taking place at the Durban University of Technology Chiropractic Day Clinic located at 8 Ritson Road, Musgrave, Durban. Prior to participation in the study, you will be required to meet the following inclusion and exclusion criteria:

<u>Inclusion Criteria:</u>
1) Participants must be male in order to ensure homogeneity in the sample population
2) Participants must currently participate in the KZN mens 1st division waterpolo league
3) Participants must be asymptomatic

<u>Exclusion criteria:</u>
1) Any participant with an upper limb musculoskeletal injury or pain
2) Any participant under the age of 18 as parental consent would be required

3) Any participant over the age of 45 as natural degenerative changes may influence the results
4) Any participant who refuses to sign the letter of informed consent

If you meet these criteria and have read the letter of information and are willing to take part in the study you will be asked to sign a letter of informed consent. Before you sign the letter of informed consent you will be given the opportunity to ask me any questions that you may have regarding any part of the research procedure. If you choose not to sign the letter of informed consent you will not be included in the study and will be thanked and allowed to leave. Once you have signed the letter of informed consent you will then undergo a case history, a general physical examination and a shoulder regional examination as standard protocol in order to determine your eligibility to be included in the study. The case history consists of questions about any current or past health complications as well as a family medical history. The general physical examination is a standard exmanination to determine the overall health status of an individual and comprises of standard physical assessments of each of the major systems in the body. The shoulder regional examination is a musculoskeletal assessment of the shoulder-complex and is used to determine if there are any injuries to structures that might affect the outcome of the study.

Following this, we will begin with the sport-specific shoulder examination. The first step of the procedure is the shoulder range of motion assessment. This consists of me using a hand held device called a goniometer to measure the range of motion of your shoulders in three directions. This simply requires you to move your arm through a specific movement while I manually measure the angle that is formed by the joint. This procedure will be conducted on both shoulders.

The next part of the procedure is the shoulder-complex orthopaedic assessment. This consists of me performing structure-specific injury assessment tests in order to identify the presence of any underlying pathology in the musculoskeletal structures of your shoulders. Though the tests may cause mild transient pain or discomfort they are considered safe and are used by all medical professions to identify the presence of damage to musculoskeletal structures.

The final part of the procedure is the digital posture examination. This step requires you to remove your shirt and stand in front of a digital camera while a photo is taken from the side of each of your shoulder complexes. This photo will be loaded onto digital posture analysis software which will then be used to assess the posture of each of your shoulders. All personal information and photos collected during the research procedure will be used only for research purposes and will not be reproduced or disseminated in any way. Personal information and photos will be stored in a safe location in order to ensure your privacy and confidentiality.

The entire process will take approximately one hour and no follow up consultation is required. There is no intervention or placebo being used and there will be no group allocations.

Risks or Discomforts to the Participant:
Due to the nature of musculoskeletal injury assessments it is expected that you may experience some mild discomfort during the testing procedure. This is because the assessment requires the use of pain provocation tests which apply light stress to specific structures in order to assess for the presence of pain or discomfort that would indicate a possible injury to those structures. All of the procedures being performed are safe and are common practice in musculoskeletal injury assessments.

Benefits:
The outcome of the study could potentially benefit you by providing insight into the development of musculoskeletal injuries and how this can be prevented. I will benefit by potentially receiving a masters degree from the Durban University of Technology and potential publication in a peer reviewed journal.

Reason/s why the Participant May Be Withdrawn from the Study:
It must be noted that you have the right to withdraw from the study at any point and, should you choose to do so, there will be no adverse consequences.
That being said, you may be withdrawn from the study for the following reasons:
-Non-compliance with the researcher
-Refusal to sign the letter of information and informed consent
-Identification of any current symptomatic shoulder pathology
-Adverse reaction to any of the procedures being performed

Remuneration:
Participation in the study is completely voluntary and, therefore, there will be no remuneration.

Costs of the Study:
You do not need to pay for any part of the study.

Confidentiality:
A code will be assigned to you so that your name is not used and none of your personal details will be used in the interpretation and write-up of the data. A hard copy of all the research data will be stored in your patient file at the Chiropractic Day Clinic for 5 years and will then be shredded. Only the clinic reception staff and myself will have access to the personal information and codes used.

Research-related Injury:
Due to the nature of the study procedure and the tests being used there is not expected to be any research-related injury.

Persons to Contact in the Event of Any Problems or Queries:
Researcher: Conor Gibb (B.Tech Chiropractic)
Email: conorgibb101@gmail.com
Phone: 0614035200

Supervisor: Dr Grant Matkovich (M.Tech Chiropractic)
Email: grantmatko@mweb.co.za
Phone: 0312018204

Please contact the researcher (0614035200), my supervisor (0312018204) or the Institutional Research Ethics Administrator on 031 373 2375. Complaints can be reported to the DVC: Research, Innovation and Engagement Prof S Moyo on 031 373 2577 or moyos@dut.ac.za

APPENDIX B: Informed Consent

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, ________ (name of researcher), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: ___________,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

______________________ ___________ _______ ________________

Full Name of Participant **Date** **Time** **Signature/Right Thumbprint**

I, ________________________ (name of researcher) herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

___________________ ___________ ____________________

Full Name of Researcher **Date** **Signature**

___________________ ___________ ____________________

Full Name of Witness (If applicable) **Date** **Signature**

Full Name of Legal Guardian **Date** **Signature**
(If applicable)

APPENDIX C: Flyer

DURBAN UNIVERSITY OF TECHNOLOGY

Do you have a history of waterpolo-related shoulder injury?

I am currently seeking males who participate in the KZN men's first division waterpolo league who are willing to undergo a free shoulder assessment as part of my Masters thesis for chiropractic.

Title of the study:
An analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players.

Location:
Durban University of Technology Chiropractic Day Clinic
8 Ritson Road, Musgrave

What's in it for you:
Free waterpolo-specific injury assessment and insight into the development of musculoskeletal overuse injuries and how these may be prevented

If you are interested in taking part in the study or have any questions please contact me through the following channels:
Cell: 0614035200
Email: conorgibb101@gmail.com

APPENDIX D: Request for Permission to Conduct Research at DUT

24 February 2020

Conor Gibb
Mtech:Chiropractic Student
21349502

Request for Permission to Conduct Research

Dear Professor Duffy

My name is Conor Gibb, a Chiropractic student at the Durban University of Technology. The research I wish to conduct for my Masters dissertation involves an analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players.

I am hereby seeking your consent to perform my data collection process at the DUT Chiropractic day clinic.

I have provided you with a copy of my proposal which includes copies of the data collection tools and consent and/ or assent forms to be used in the research process, as well as a copy of the approval letter which I received from the Institutional Research Ethics Committee (IREC).

If you require any further information, please do not hesitate to contact me at conorgibb101@gmail.com. Thank you for your time and consideration in this matter.

Yours sincerely,

Conor Gibb
Durban University of Technology

APPENDIX E: Request for Permission to Use the DUT Chiropractic Day Clinic

13 November 2019

Conor Gibb
Mtech:Chiropractic Student
21349502

Request for Permission to Conduct Research

Dear Dr Varatharajullu

My name is Conor Gibb, a Chiropractic student at the Durban University of Technology. The research I wish to conduct for my Masters dissertation involves an analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players.

I am hereby seeking your consent to perform my data collection process at the DUT Chiropractic day clinic.

I have provided you with a copy of my proposal which includes copies of the data collection tools and consent and/ or assent forms to be used in the research process, as well as a copy of the approval letter which I received from the Institutional Research Ethics Committee (IREC).

If you require any further information, please do not hesitate to contact me at conorgibb101@gmail.com. Thank you for your time and consideration in this matter.

Yours sincerely,

Conor Gibb
Durban University of Technology

APPENDIX F: Case History Form

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC

CHIROPRACTIC DAY CLINIC CASE HISTORY

Patient: ______________________________ Date: __________

File #: __________ Age: __________

Gender: __________ Occupation: ______________________

Student: ______________________ Signature ______________________

FOR CLINICIANS USE ONLY:

Initial visit

Clinician: Signature:

Case History:

Examination:

Previous: Current:

X-Ray Studies:

Previous: Current:

Clinical Path. lab:

Previous: Current:

CASE STATUS:

PTT:	Signature:	Date:

CONDITIONAL:

Reason for Conditional:

Signature: Date:

Conditions met in Visit No:	Signed into PTT:	Date:

Case Summary signed off:	Date:

Student's Case History:

Page 1 of 4

1. **Source of History:**

2. **Chief Complaint: (patient's own words):**

3. **Present Illness:**

	Complaint 1(principle complaint)	**Complaint 2 (additional or secondary complaint)**
Location		
Onset : Initial:		
Recent:		
Cause:		
Duration		
Frequency		
Pain (Character)		
Progression		
Aggravating Factors		
Relieving Factors		
Associated S & S		
Previous Occurrences		
Past Treatment		
Outcome:		

4. **Other Complaints:**

5. **Past Medical History:**

General Health Status

Childhood Illnesses

Adult Illnesses

Psychiatric Illnesses

Accidents/Injuries

Surgery

Hospitalizations

6. Current health status and life-style:

Allergies

Immunizations

Screening Tests incl. x-rays

Environmental Hazards (Home, School, Work)

Exercise and Leisure

Sleep Patterns

Diet

Current Medication
Analgesics/week:
Other (please list):

Tobacco
Alcohol
Social Drugs

7. Immediate Family Medical History:

Age of all family members
Health of all family members
Cause of Death of any family members

	Noted	Family member		Noted	Family member
Alcoholism			Headaches		
Anaemia			Heart Disease		
Arthritis			Kidney Disease		
CA			Mental Illness		
DM			Stroke		
Drug Addiction			Thyroid Disease		
Epilepsy			TB		
Other (list)					

8. Psychosocial history:

Home Situation and daily life
Important experiences
Religious Beliefs

9. **Review of Systems (please highlight with an asterisk those areas that are a problem for the patient and require further investigation)**

General

Skin

Head

Eyes

Ears

Nose/Sinuses

Mouth/Throat

Neck

Breasts

Respiratory

Cardiac

Gastro-intestinal

Urinary

Genital

Vascular

Musculoskeletal

Neurologic

Haematological

Endocrine

Psychiatric

Appendix G: Physical Examination

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC

PHYSICAL EXAMINATION: SENIOR

Patient Name: ______________ **File no:** ________ **Date:** ________

Student: **Signature:**

VITALS:					
Pulse rate:			Respiratory rate:		
Blood pressure:	R	L	Medication if hypertensive:		
Temperature:			Height:		
Weight:	Any recent change?	Y / N	If Yes: How much gain/loss	Over what period	

GENERAL EXAMINATION:		
General Impression		
Skin		
Jaundice		
Pallor		
Clubbing		
Cyanosis (Central/Peripheral)		
Oedema		
Lymph nodes	Head and neck	
	Axillary	
	Epitrochlear	
	Inguinal	
Pulses		
Urinalysis		

SYSTEM SPECIFIC EXAMINATION:

CARDIOVASCULAR EXAMINATION

RESPIRATORY EXAMINATION

ABDOMINAL EXAMINATION

NEUROLOGICAL EXAMINATION

COMMENTS

Clinician: **Signature:**

Page 1

Appendix H: Shoulder Regional Examination Form

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC

SHOULDER REGIONAL EXAMINATION

Patient: ______________________ File No: __________ Date: __________

Student: ______________________ Signature: ______________________

Clinician: ______________________ Signature: ______________________

Observation

Posture		S-C Joints	
Skin		Clavicles	
Swelling		A-C Joints	
Shoulder levels		Scapulae	
Comments			

Palpation

S-C Joint:		SCM:		Scalenes:	
Sternum:		Ribs and costal cartridge:			
Clavicle:		Coracoid process:			
A-C Joint:		Acromion:			
Greater Tuberosity:					
Lesser Tuberosity:					
Intertubercular (bicipital groove):					
Trapezius:		Deltoid:			
Biceps:		Triceps:			
Supraspinatus insertion:					
Musculotendinous portion of supraspinatus:					
Axilla:	Lymph nodes:				
	Brachial artery:				
	Serratus anterior (medial wall):				
	Pectoralis major (anterior wall):				
	Lattisimus dorsi (posterior wall):				
Scapula	Borders:		Spine:		
	Supraspinous fossa:				
	Infraspinous fossa:				
Cervico-thoracic spine:					

Page 1 of 3

Instability Tests

1. **Anterior Instability Tests**	R			L		
	Pos	Neg	n/a	Pos	Neg	n/a
Anterior drawer Test						
Rowe Test						
Fulcrum Test						
Apprehension (crank) Test						
Clunk Test (tear of labrum)						
Rockwood Test						
2. **Posterior Instability Tests**						
	Pos	Neg	n/a	Pos	Neg	n/a
Posterior Apprehension Test						
Norwood Stress Test						
Push-pull Test						
Jerk Test						
3. **Inferior and Multi-directional instability tests**						
	Pos	Neg	n/a	Pos	Neg	n/a
Inferior Shoulder Instability Test						
Feagin Test (antero-inferior instability)						

A-C Joint Stress Test: ______________________________

S-C Joint Stress Test: ______________________________

Tests for Muscle or Tendon Pathology

1.	Gilchrest Sign (bicipital tendonitis)	
2.	Speed's Test (bicipital tendonitis)	
3.	Hawkins-Kennedy Impingement Test (supraspinatus tendonitis)	
4.	Supraspinatus Test (supraspinatus tendonitis)	
5.	Drop –arm Test (rotator cuff tear)	
6.	Impingement Test	
7.	Ludington's Test (rupture of long head of biceps)	
8.	Pectoralis Major Contracture Test	

Tests for neurological function

Brachial Plexus Tension Test	Radial Nerve													
	Median Nerve													
Tinel's Sign (Scalene triangle)														
Dermatones	C4		C5		C6		C7		C8		T1		T2	
Reflexes	Biceps(C5/6)						Triceps (C7/8)							

Thoracic Outlet Syndrome Tests

Adson's Test		Halstead's Test	
Costoclavicular Test		Eden's Test (cervical rib)	
Hyperabduction Test		Roos Test	
Allen's Test			

APPENDIX I: Sport-specific Shoulder Regional Data Collection Sheet

Participant Name:_____________________________ Date:______________________

Waterpolo club:_______________________________ Age:_______________________

Study ID code:________________________________

Arm Dominance

Left	Right

Range of motion

Motion tested	Dominant shoulder		Non-dominant shoulder	
	Active	Passive	Active	Passive
Internal rotation				
External rotation				
Horizontal adduction				

Orthopaedic Testing

Test	Dominant shoulder	Non-dominant shoulder
Empty can test		
Painful arc test		
Hawkins-Kennedy test		
External rotation resistance test		
Neer test		
Yergasson's test		
Biceps load test II		
Apprehension-relocation-surprise test		

Posture

Quantification of posture measurements:

Head Angle

Rating	Measurement
Ideal head carriage	≤ 36°
Mild forward head carriage	37° – 41°
Moderate forward head carriage	42° – 46°
Severe forward head carriage	>46°

Shoulder angle

Rating	Measurement
Ideal shoulder carriage	≤ 22°
Mild forward shoulder carriage	23° – 37°
Moderate forward shoulder carriage	38° – 52°
Severe forward shoulder carriage	>52°

Participants posture measurements

Measurement	Dominant side		Non-dominant side	
	Measurement	Rating	Measurement	Rating
Acromiovertebral Angle				
Craniovertebral Angle				

APPENDIX J: Data Capture Sheet For Statistician

studyID	date	club	age	dom	IRDA	IRDP	IRNA	IRNP	ERDA	ERDP	ERNA	ERNP	HADA	HADP	HANA	HANP	ECTD	ECTN	PATD	PATN

HKTD	HKTN	ERRT	ERRN	NTD	NTN	YTD	YTN	BLTD	BLTN	ARSTD	ARSTN	AADM	AADR	AANM	AANR	CADM	CADR	CANM	CANR

APPENDIX K: IREC Approval

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2375
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

23 June 2020

Mr C Gibb
86 Doble Road
Bluff
Durban
4052

Dear Mr Gibb

An analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players
Ethical Clearance number IREC 011/20

The Institutional Research Ethics Committee acknowledges receipt of your gatekeeper permission letters.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed with data collection.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC Standard Operating Procedures (SOP's).

Please note that any deviations from the approved proposal require the approval of the IREC as outlined in the IREC SOP's.

Yours Sincerely

Professor J K Adam
Chairperson: IREC

APPENDIX L: Gatekeepers Permission for Use of Off-Campus Site

DR GRANT MATKOVICH

M.Tech (Chiro)

Practice Number: 0152927

CHIROPRACTOR

15 October 2020

To Whom It May Concern

RE: Permission to use premises / 360 Clark Road / For research.

I hereby give permission to Conor Gibb, a Chiropractic student at DUT, to conduct data collection at my office premises, 360 Clark Road, Glenwood 4001.

The data collection is for his study **"An analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players". IREC 011/20,** for which I am also his supervisor.

Kind Regards

Dr Grant Matkovich

360 Clark Road – Opp. St Augustine's Hospital – Glenwood – 4001

Tel: 031 201 8204 – Fax: 0865097576 – Email:

Appendix M: Application for Approval of Amendment: Addition of off-campus data collection site

DUT DURBAN UNIVERSITY OF TECHNOLOGY

INSTITUTIONAL RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF AMENDMENT

Title of the study: An analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players	
Institution: Durban University of Technology	Date:15 October 2020
Name and qualification of principal investigator/researcher: Conor Gibb B.Tech Chiropractic	Name and qualification of supervisor(s): Dr Grant Matkovich M.Tech Chiropractic
Name of qualification: M.Tech Chiropractic	Student Number:21349502
Ethical approval number: 011/20	Research site: DUT Chiropractic Day Clinic
Nature of amendment: Addition of off-campus data collection site.	
Effect on risk benefit profile of participants: There will be no effect on the risk benefit profile.	
Please submit the following documentation: • Amended proposal (changes to be underlined) • Changes to letter of information and consent • Any other relevant documentation	
Signature:	**Date:**
Researcher:	15/10/2020
Supervisor:	15 OCT 2020
Head of Department:	
TO BE COMPLETED BY THE CHAIRPERSON OF THE IREC.	
Date received:	Review required: Expedited

TO BE COMPLETED BY THE CHAIRPERSON OF THE IREC			
The amendment is:	Yes	No	N/A
Approved – there are no evident grounds for concern or further investigation.			
Approved subject to minor changes			
Needs to be re-submitted after recommendations are met			
Approved however a site inspection is recommended.			
Denied (please see attached)			

	Signature:	**Date:**
Chairperson of FRC		
Chairperson of IREC		

Appendix N: Approval of Data Collection Site Amendment

DUT
DURBAN
UNIVERSITY OF
TECHNOLOGY

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

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16 November 2020

Mr C Gibb
86 Doble Road
Bluff
Durban
4052

Dear Mr Gibb

Application for Amendment of Approved Research Proposal

An analysis of the combined effects of swimming and overhead throwing on the shoulder complexes of male first division waterpolo players

I am pleased to inform you that your application for amendment has been approved.

Yours Sincerely

Prof J Adam
Chairperson: IREC

2020 -11- 16