THE EFFECT OF CORE STABILITY ON MALE WATER POLO PLAYERS' JUMP HEIGHT AND THROWING VELOCITY

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I, Nicole Ashley McKenzie, do declare that this dissertation is representation of my own work in both conception and execution (except when acknowledgements indicate to the contrary).

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DEDICATION

I dedicate this dissertation to my friends, family and especially, my mother, Elaine Greeff. Thank you for all your love, support and encouragement throughout this process.

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ABSTRACT

BACKGROUND

Water polo is a highly competitive and physical sport where athletes are continuously looking for ways to improve their performance and reduce injuries. Core stability has been extensively studied in its role to improve athletic performance and to reduce the risk of injuries in overhead throwing athletes.

AIM

To determine the role of core stability in male water polo players' by identifying the relationship between core stability, jump height and throwing velocity.

OBJECTIVES

To measure core stability, jump height (cm) and throwing velocity (km/h) in male water polo players and to identify if any correlations exist between them.

METHOD

Core stability was assessed in twenty-six asymptomatic male water polo athletes using the PRONE and SUPINE tests. Participants jump height (cm) and throwing velocity (km/h) were measured using a modified yard stick and speed radar gun. IBM SPSS version 24 was used to analyse the data. A probability (p) value less than 0.05 was considered statistically significant.

RESULTS

The mean values for jump height were calculated at maximum head height (64.22 cm) and head height at ball release (59.50 cm) respectively. Throwing velocities ranged from 50.33 km/h to 77.33 km/h. There was a significant relationship between: core stability and maximum head height (p=0.027), head height at ball release (p=0.025) and throwing velocity (p=0.001). Significant correlations were depicted among the three outcome measures. The strongest relationship was between maximum head height and head height at ball release (r = 0.945).

CONCLUSION

The results of this study show that core stability significantly affects throwing velocity and jump height in water polo athletes with the largest difference being between moderate and excellent core stability.

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DEFINITION OF TERMS

Arthrokinematics – Co-ordinated movement of the joint surfaces during movements of the body (Stodden, Campbell and Moyer 2008).

Asymptomatic – Not showing symptoms (Bucy 1982).

Biomechanics – The study of human movement by analysing the structure, function and motion of a particular part of the human musculoskeletal system (Bartlett 2007).

Core muscle endurance – The ability of the core muscles to maintain contraction against resistance for a period time (Zinner *et al.* 2015).

Endurance – The ability to perform at task for a period of time (Zinner *et al.* 2015).

Extrinsic load – A load or force applied externally to the musculoskeletal system (Silfies *et al.* 2015).

Kinetic chain – A term used to describe movement of the human body. The human body is described as a chain, where movement of one part affects the parts adjacent to it (Khademi Kalantari and Berenji Ardestani 2013).

Neutral position – When the spinal joints are aligned and there is no tension in the musculature. The head is balanced between the shoulders and eyes gazing forward (Meiyappan *et al.* 2015).

Power – Power is the rate of performance per unit of time; joules (J) per second or watts (W). Therefore, power is the quantity of energy used to elevate the water polo athlete out of the water and energy transferred to the ball (Zinner *et al.* 2015).

Pressure Biofeedback unit (PBU) – Inelastic three section air filled bag connected to a pressure dial which monitors the pressure within the bag (Chattanooga Group, A Division of Encore Medical, 2002). It provides visual feedback of core muscle activation by monitoring the movement of a body part on or off the bag. Each movement alters the pressure within the bag and indicates muscle contraction (Richardson et al. 1999).

Rotator cuff syndrome – Shoulder pain caused by injury to one or more of the four rotator cuff muscles (supraspinatus, infraspinatus, teres minor or deltoid) (Bossche and Vanderstraeten 2015).

Swimmer's shoulder – Common occurrence of pain experienced in the shoulder musculature of swimmers as a result of the repetitive arm movements (De Martino and Rodeo 2018).

Thrower's elbow – A multitude of distinct injuries caused by valgus and extension movements at the elbow during the throwing motion; ulnar co-lateral ligament tears or sprains, flexor-pronator muscle tears or strains, olecranon stress fracture, osteochondritis dissecans of the capitellum, medial epicondyle apophyseal injuries (Warrell, Osbahr and Andrews 2016)

LIST OF SYMBOLS AND ABBREVIATIONS

BMI – Body mass index

cm – centimetres

Df – degrees of freedom

F – F-statistic for ANOVA (used to determine the p-value)

HH ball release – Head height at ball release

Kg – kilograms

Km/h – kilometres per hour

KZN – KwaZulu-Natal

LBP – Lower back pain

max HH – maximum head height

PBU – Pressure Biofeedback Unit

P-value – probability

r – correlation co-efficient (for ANOVA tests)

Sig. – Significance

Std. – Standard

TA – Transverse abdominis

WBHS – Westville Boys High School

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CHAPTER ONE

1.1 INTRODUCTION

Water polo is a physically demanding aquatic sport. The sport consists of four quarters and involves high to low intensity swimming, combined with overhead throwing and aggressive contact between players (Miller *et al.* 2018). Due to the physicality between players and the intensity of the game, athletes are required to be well conditioned. The main focus for improving performance in water polo athletes is based on improving swimming speeds, strength and throwing velocities (Platanou 2005; Canossa et al. 2016). Vigorous training and repetitive throwing may lead to overuse injuries (Pecina and Bojanic 2003; Lin, Wong and Kazam 2018). Participation in water polo may result in acute trauma such as contusions, lacerations, sprains, dislocations and fractures (Junge et al. 2006).

Core stability is important in athletes as it improves performance and reduces the risk of injury by facilitating the transfer of forces through the body. Initiation of movement comes from the core musculature and energy is transferred in a proximal-to-distal manner (DiRocco 1998; Clements, Ginn and Henley 2001; Silfies *et al.* 2015). On land, overhead throwing athletes generate force from their legs, trunk and most noteworthy the ground; this force is then transferred through the shoulder to the arm and lastly, to the ball (Burkhart, Morgan and Kibler 2003; Wagner *et al.* 2011; Tomasa 2017). In water polo, there is no ground reactive force and thus the athlete relies on the buoyant force supplied by the water and strength from the breaststroke kick in order to generate the upward force necessary to simultaneously expel his/her body out of the water and throw the ball (Sanders 2005; Webster, Morris and Galna 2009; Zinner *et al.* 2015).

Water polo is one of many sports played in South Africa and therefore, it is important for musculoskeletal therapists to have a background knowledge of the sport and more importantly the role that the core plays in improving athletic performance and reducing the risk of injuries. This understanding will assist therapists in developing treatment and rehabilitation programs in order to return water polo athletes to their full athletic potential.

1.2 AIM

The aim of this study is to determine the role of core stability in male water polo athletes by identifying if a relationship among core stability, jump height and throwing velocity exists in male water polo players.

1.3 OBJECTIVES

1. To assess core stability in male water polo athletes by means of the Prone and Supine tests
2. To measure jump height and throwing velocity in male water polo athletes.
3. To establish if a correlation among core stability, jump height and throwing velocity exists in male water polo athletes.

1.4 HYPOTHESIS

It was hypothesised that a statistical significance exists between core stability, jump height and throwing velocity in male water polo athletes.

1.5 NULL HYPOTHESIS

There would be no statistical significance between core stability, jump height and throwing velocity in male water polo athletes.

1.6 LIMITATIONS

1. Core stability had to be measured on land as there was no available test to measure core stability in water.
2. Environmental factors such as air temperature and weather conditions may have impacted the results of the study, as throwing velocity was measured in an outdoor pool.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews the current literature, with a discussion on core stability and the role it plays in the sport of water polo.

2.2 INTRODUCTION TO CORE STABILITY

Core stability is the ability of the muscles of the torso and pelvis to stabilise the spine and maintain the centre of gravity over the base of support during functional and dynamic movements (Prentice 2015). During movement, core stability is necessary to optimise the production, transfer and control of forces to and from the limbs (Kibler, Press and Sciascia 2006; Shankar and Chaurasia 2012). By doing so, core stability facilitates normal co-ordinated movements of the joints and therefore, reduces injuries to the surrounding ligaments, tendons and muscles (Hibbs *et al.* 2008; Prentice 2015).

2.2.1 Difference between core stability and core strength

Core stability and core strength are two terms that are often used together without distinction made between them. Core stability is defined as the ability of the core muscles to stabilise the spine and pelvis during movement of the body (Faries and Greenwood 2007). Whereas core strength is the ability of the core muscles to contract in order to produce a force (Faries and Greenwood 2007). Although core stability and core strength are separate qualities, they work in conjunction with each other and are therefore complementary qualities.

2.3 ANATOMY INVOLVED IN CORE STABILITY

Panjabi (1992) originally described core stability as spinal stability and identified three components involved in providing spinal stability: the passive spinal column, the active spinal muscles and the central nervous system (CNS). The anatomy involved in core stability includes the bony anatomy of the lumbopelvic-hip complex including the lumbar spine, sacrum and pelvic girdle and the surrounding ligaments, musculature and thoraco-lumbar fascia (Kibler, Press and Sciascia 2006; Akuthota *et al.* 2008).

2.3.1 Bony anatomy of the lumbopelvic-hip complex

2.3.1.1 Lumbar vertebrae

The Lumbar spine consists of five lumbar vertebrae with large kidney shaped vertebral bodies that increase in size from L1 through to L5. The vertebral bodies become thicker as you move inferiorly down the lumbar spine as the weight that they support increases (Moore, Dalley and Agur 2010). The vertebral foramen is triangular in shape. The Lumbar vertebra have long and slender transverse processes that extend from the junction of the laminae and pedicle. They project posterosuperiorly as well as laterally and on the posterior surface of each transverse process is an accessory process (Moore, Dalley and Agur 2010). The superior articular processes are directed posteromedially and the inferior articular processes are directed anterolaterally. Mamillary processes are located on the posterior surface of each superior articular process. The lumbar vertebrae have short, and thick hatchet-shaped spinous processes that project posteriorly (Moore, Dalley and Agur 2010).

The spinous processes and transverse processes serve as a point for muscle and ligament attachment. The articulation between the superior and inferior processes of adjacent vertebrae form a locking mechanism which facilitates flexion, extension and lateral flexion of the spinal column but restricts rotation (Moore, Dalley and Agur 2010).

2.3.1.2 Sacrum

The sacrum is wedge-shaped and consists of five consecutively fused vertebrae. The sacrum is located between the hip bones and forms the posterior wall of the pelvic cavity. It provides stability and strength to the pelvis and transmits the weight of the body to the pelvic girdle (Moore, Dalley and Agur 2010).

2.3.1.3 Pelvic girdle

The pelvic girdle is basin-shaped and consist of the left and right pelvic bones and the sacrum. The pelvic bones are formed by the fusion of the ilium, ischium and pubis. On the lateral aspect of the pelvic bones is the acetabulum, which is a depression for the articulation with the head of the femur (Moore, Dalley and Agur 2010). The pelvic girdle is the link between the spinal column and the left and right femurs. It serves as the attachment site for muscles of the abdomen and lower limbs and bears the weight of the upper body and transmits it to the lower limbs (Moore, Dalley and Agur 2010).

2.3.2 Ligaments

The main ligaments of the lumbar spine and pelvis include the anterior longitudinal ligament, the posterior longitudinal ligament, the iliolumbar ligament and the sacroiliac ligaments. These ligaments connect the spinal column to the pelvic girdle to form the lumbopelvic-hip complex. They provide stability by restricting excessive movements of the joints (Moore, Dalley and Agur 2010).

Table 1: Ligaments of the lumbar spine and pelvis

Ligament	Attachment	Function
Anterior longitudinal ligament	A strong, thick fibrous band that extends from the anterior tubercle of the C1 vertebra to the pelvic surface of the sacrum. Its fibres attach to the anterolateral aspects of the vertebral bodies and intervertebral discs.	Limits hyperextension of the vertebral column and maintains stability of the joints between vertebral bodies.
Posterior longitudinal ligament	It extends from the C2 vertebral body to the sacrum. It runs through the vertebral canal and Its fibres attach to the posterior surfaces of the IVDs and the posterosuperior margins of the vertebral bodies.	Prevents hyperflexion of the vertebral column and helps prevent or redirect posterior herniation of the nucleus pulposus.
Iliolumbar ligament	A thick and broad ligament that fans from the transverse process of the L5 vertebra to the ilia.	Stabilises the L5 vertebral body on the sacrum.
Anterior sacroiliac	Thin ligament that attaches the anterior sacrum and ilium.	It is thin and forms the anterior part of the fibrous capsule of the synovial sacroiliac joint.
Posterior sacroiliac ligament	Fibres run obliquely upwards and outwards from the posterior sacrum to the ilium.	Forms the posterior part of the fibrous capsule of the sacroiliac joint.

(Moore, Dalley and Agur 2010).

2.3.3 Musculature

The muscles involved in core stability consist of muscles found in the abdomen (Table 2) and lumbar (Table 3) regions, the diaphragm and the pelvic floor muscles. These muscles attach to the lumbopelvic-hip complex and form a supportive muscular corset (Akuthota and Nadler 2004; Shankar and Chaurasia 2012; Prentice 2015). Bergmark (1989) divided the core muscles into two groups: the local muscle system and the global muscle system.

2.3.3.1 Local and global muscle systems

Local and global muscles are divided based on their location and role in providing core stability.

2.3.3.1.1 The local muscle system

The local muscle system consists of deep muscles with slow twitch muscle fibres and have their origin and insertion on the lumbar vertebra (TA and multifidus) (Akuthota *et al.* 2008). These muscles are shorter in length and are therefore suited for maintaining spinal curvature, they respond to changes in posture and extrinsic loads in order to maintain mechanical stability of the lumbar spine (Bergmark 1989; Akuthota *et al.* 2008).

2.3.3.1.2 The global muscle system

The global muscle system consists of large superficial muscles of the trunk which attach to the hips and pelvis and have fast-twitch fibres (External oblique, internal oblique, rectus abdominus, erector spinae and quadratus lumborum) (Akuthota *et al.* 2008). These muscles are responsible for movements of the spine and manage external loads applied to the spine (Bergmark 1989).

2.3.3.2 The abdominal muscles

The abdominal muscles consist of the rectus abdominis, external obliques, internal obliques and transverse abdominals (TA). These muscles form the anterior wall of the muscular corset (Mottram and Comerford 2008). Most of the abdominal muscles are classified as global muscles except the TA.

Table 2: Abdominal muscles

Muscle	Origin	Insertion	Innervation	Main action
Rectus abdominis	Pubic symphysis and pubic crest	Xiphoid process and 5^{th}-7^{th} costal cartilages	Thoracoabdominal nerves (anterior rami of T6-T12 spinal nerves)	Flexes the trunk and compresses the abdominal viscera. It stabilizes and controls the tilt of the pelvis (anti-lordosis).
External oblique	External surface of 5^{th}-12^{th} ribs	Linea alba, pubic tubercle, and anterior half of iliac crest.	Thoracoabdominal nerves (T7-T11 spinal nerves) and subcostal nerve.	Compresses and supports the abdominal viscera. Bilateral contraction flexes the trunk while unilateral contraction rotates the trunk.
Internal oblique	Thoracolumbar fascia, anterior two thirds of iliac crest, and connective tissue deep to lateral third of inguinal ligament.	Inferior borders of 10^{th}-12^{th} ribs, linea alba, and pecten pubis via conjoint tendon.	Thoracoabdominal nerves (anterior rami of T6-T12 spinal nerves) and the first lumbar nerves	
Transverse abdominis	Internal surface of 7^{th}-12^{th} costal cartilages, thoracolumbar fascia, iliac crest, and connective tissue deep to lateral third of inguinal ligament.	Linea alba with aponeurosis of internal oblique, pubic crest, and pecten pubis via conjoint tendon.		Compresses and supports the abdominal viscera. Assists in flexion and rotation of the trunk

(Moore, Dalley and Agur 2010).

2.3.3.3 The lumbar muscles

The posterior wall of the muscular corset is formed by the lumbar muscles (Mottram and Comerford 2008). The deeper lumbar muscles (multifidus, interspinales intertransversarii and rotatores) form part of the local muscle system while the more superficial muscles (erector spinae and quadratus lumborum) form part of the global muscle system.

Table 3: Lumbar muscles

Muscle	Origin	Insertion	Innervation	Main action
Erector Spinae Iliocostalis Longissimus Spinalis	Arise by a broad tendon from the posterior part of the iliac crest, posterior surface of the sacrum, sacroiliac ligaments, sacral and inferior lumbar spinous processes, and the supra spinous ligament.	*Iliocostalis:* fibres run superiorly to attach to the angles of the lower ribs and cervical transverse processes. *Longissimus:* fibres run superiorly to the ribs between the tubercle and angles, to the transverse processes in the thoracic and cervical regions and to the mastoid process of the temporal bone. *Spinalis:* fibres run superiorly to the spinous processes in the upper thoracic region and the cranium.	Posterior rami of spinal nerves.	*Acting bilaterally:* extends vertebral column and head; when back is flexed, controls movement via eccentric contraction. *Acting unilaterally:* laterally flexes vertebral column.
Quadratus Lumborum	Medial half of the inferior border of the 12th ribs and tips of the lumbar transverse processes.	Iliolumbar ligament and internal lip of iliac crest.	Anterior branches of T12 and L1-L4 nerves.	Extends and laterally flexes the vertebral column; fixes the 12th rib during inspiration.
Multifidus	Arises from the posterior sacrum, posterior superior iliac spine of the ilium, aponeurosis erector spinae, sacroiliac ligaments, mammillary processes of the lumbar vertebrae, transverse processes of T11-T3, articular processes of C4-C7.	Thickest in the Lumbar region; fibres pass superomedially to entire length of spinous process 2-4 segment superior to proximal attachment.	Posterior rami of spinal nerves.	Stabilizes vertebrae during local movements of vertebral column.

Interspinales	Superior surface of the spinous processes of the cervical and lumbar vertebrae.	Inferior surface of the spinous processes of the vertebra superior to the vertebra of the proximal attachment.	Posterior rami of spinal nerves.	Aid in extension and rotation of the vertebral column.
Intertransversarii	Transverse processes of the cervical and lumbar vertebrae.	Transverse processes of adjacent vertebrae.	Posterior and anterior rami of spinal nerves.	Aid in lateral flexion of vertebral column; acting bilaterally, stabilizes vertebral column.
Rotatores	Arise from the transverse processes of vertebrae; best developed in the thoracic region.	Fibres pass superomedially to attach to the junction of laminae and the spinous processes of the vertebrae immediately or 2 segments superior to the vertebrae of proximal attachment.		

(Moore, Dalley and Agur 2010).

2.3.3.4 The diaphragm

The diaphragm is a large musculotendinous structure that separates the thoracic and abdominal viscera and forms the roof of the muscular corset. It has a sternal, costal and lumbar attachment (Moore, Dalley and Agur 2010). Contraction of the diaphragm increases intra-abdominal pressure thus aiding lumbar stability (Akuthota *et al.* 2008).

2.3.3.5 The pelvic floor muscles

The pelvic floor muscles consist of the coccygeus and levator ani muscles. Together with the overlying fascia, these muscles form the pelvic diaphragm which acts as the floor of the muscular corset and is co-activated with TA contraction to aid in core stability (Akuthota *et al.* 2008; Moore, Dalley and Agur 2010).

2.3.4 The thoracolumbar fascia

The thoracolumbar fascia is an extensive fascial complex located posterior to the thoracolumbar spine. It extends laterally from the thoracic and lumbar spinous processes and forms a covering over the muscles in those regions. In the thoracic region it is described as being thin and transparent, but it is thick and strong in the lumbar region. The lumbar portion consists of three layers (an anterior, middle and posterior layer) with muscle enclosed among them (Moore, Dalley and Agur 2010). The TA has been reported as having large attachments to the middle and posterior layers of the thoraco-lumbar fascia (Akuthota and Nadler 2004). This fascia plays an important role in core stability as it is a link among the lower and upper limbs and contraction of the muscular components that attach to the thoracolumbar fascia and provides proprioceptive feedback with regards to trunk positioning (Akuthota and Nadler 2004).

2.4 ACTIVATION OF THE CORE MUSCLES TO PROVIDE CORE STABILITY

Core stability is achieved by activating the core muscles via the central nervous system (CNS) to stabilise the spinal column. Sensory and proprioceptive information of the limbs and trunk is relayed to the CNS, which reacts by activating the appropriate musculature, which in turn generates forces to provide the spine with stability in response to movement and external stimuli (Reeves, Narendra and Cholewicki 2007; Silfies *et al.* 2015). The amount of force produced when the core muscles are activated is dependent on the muscle mass whereas, the level of force required for core stability is dependent on the intensity of the activity (Leetun et al. 2004; Stephenson and Swank 2004; Silfies et al. 2015). The force required to stabilise the spine during daily activities (low load) is not sufficient for athletes during sports, as stability must be maintained during highly dynamic and loaded activities (Hibbs et al. 2008; Wirth et al. 2017).

Core stability is therefore a complex process requiring optimal muscle performance (strength, endurance, power) and neuromuscular control (joint and muscle receptors and neural pathways). Activating the core muscles ensures correct biomechanics of the body during movement.

2.5 THE ROLE OF CORE STABILITY IN BIOMECHANICS

The biomechanics of the human body have been described as a chain, where movement of one part affects the parts adjacent to it and is referred to as the kinetic chain (Khademi Kalantari and Berenji Ardestani 2013). Activation of the kinetic chain allows forces to be transferred from one part in the chain to another (Chu *et al.* 2016). Two types of kinetic chains have been described, namely the open or closed kinetic chains. The kinetic chain is considered to be closed when the terminal segment of the kinetic chain is fixed, therefore preventing free movement (e.g. The lower limbs when performing a squat) (Turgut *et al.* 2016). When the terminal segment is not restricted and free movement of the body is possible (e.g. The upper limbs during the throwing motion) and the kinetic chain is therefore open (Turgut *et al.* 2016).

The core muscles act as a bridge linking the upper and lower extremities and are therefore the centre of the kinetic chain. These muscles dynamically stabilise the spine against opposing forces acting on the body and permit forces to be produced, reduced and transferred through the kinetic chain to the extremities (Shankar and Chaurasia 2012; Prentice 2015).

Contraction of the TA and oblique abdominal muscles causes an increase in intra-abdominal pressure via the thoraco-lumbar fascia (Hsu *et al.* 2018). This increase in intra-abdominal pressure strengthens the core muscular control and promotes functional stability of the lumbar spine and facilitates co-ordinated movements of the kinetic chain (Akuthota and Nadler 2004). Therefore, having a stable core optimises the performance of the kinetic chain by allowing forces to be transferred through the kinetic chain, especially during open kinetic chain activities, such as throwing (Tse, McManus and Masters 2005; Shankar and Chaurasia 2012; Prentice 2015; Chu *et al.* 2016).

There is strong evidence that suggests individuals with lower back pain (LBP) have a weakened TA (Marshall and Murphy 2003; Mottram and Comerford 2008; Chung *et al.* 2018). Hodges and Richardson (1997) noted that in healthy individuals, the activity in the TA preceded movements of the arms and legs by approximately 30 and 100 ms respectively, suggesting that it stabilises the trunk and prepares the trunk for forces loaded at the extremities.

2.6 ASSESSING CORE STABILITY

Assessment of the muscles responsible for providing core stability has been identified as being important in the treatment and rehabilitation of LBP (Macedo *et al.* 2009; Gordon and Bloxham 2016; Coulombe *et al.* 2017). Health professionals assess the local muscles as they play a vital role in stabilising the spine. However, assessment of the local muscle contraction is more difficult than assessment of the global muscles; this is because the local muscles are deep and below the global muscles making them difficult to access and palpate. An exception is the TA, which is easily palpated, a muscle of the local muscle group and important in core stabilisation (von Garnier *et al.* 2009). The TA muscle is activated prior to any movements of the limbs (Hodges, Richardson and Jull 1996; Selkow, Eck and Rivas 2017). This activation braces the spine and prepares the spine for loading.

Numerous methods of assessing core stability are available such as ultrasound, electromyography and pressure biofeedback units (PBU). Although there are a variety of methods that exist, not all may be available as they are expensive or invasive. Thus, the PBU is commonly used to indirectly measure TA muscle activity (Martin 2006; Brotzman, Manske and Daugherty 2011; de Paula Lima *et al.* 2012).

Hodges, Richardson and Jull (1996) conducted a study that compared electromyography and PBU in the assessment of the abdominal draw-in test. Results revealed that both devices were suitable in measuring a reduction in TA co-ordination. Other studies have also demonstrated the PBU as a reliable measuring tool in the assessment of TA muscle recruitment when stabilising the spine (Storheim *et al.* 2002; von Garnier *et al.* 2009; de Paula Lima *et al.* 2012).

2.7 TRAINING THE CORE MUSCLES FOR CORE STABILITY

Exercise programs for rehabilitation, especially for LBP, focus on selective activation of the multifidus and TA muscles (Bliss and Teeple 2005; Hibbs *et al.* 2008; Hilligan 2008; Selkow, Eck and Rivas 2017). This is because the multifidus and TA have been reported as key muscles responsible in core stability (Smith 2004; Hibbs *et al.* 2008). Exercise programs in rehabilitation initially favour selective activation of the local muscles during closed kinetic chain exercises that use the individuals' body weight (Hibbs *et al.* 2008).These exercise programs aim to establish segmental spinal stability and stability needed for functional movements (Cotton 2005; Hibbs *et al.* 2008; Selkow, Eck and Rivas 2017).

However, Other researches proposes that selective activation of the local muscles is inefficient to bring about core stability (Willardson 2007; Lederman 2010). Rather, core stability is the result of activating both the local and global muscle systems (Lederman 2010). It has been reported that the local and global muscles are activated in a proximal-to-distal manor during functional activities, and suggest that the local and global muscles should be recognised as a functional unit that works together to provide core stability (Cholewicki and Vanvliet Iv 2002; Lederman 2010; Okada, Huxel and Nesser 2011).

Improving core stability may be more effective on an unstable surface. Research in rehabilitation has shown the effectiveness of swiss ball exercises (Shankar and Chaurasia 2012). Low load swiss ball exercises constantly challenge the core muscles which improves core stability and balance, compared to exercises done on the floor (Willardson 2007; Escamilla *et al.* 2010; Shankar and Chaurasia 2012). Hibbs *et al*. (2008) suggested that it is necessary to include different exercises that challenge the core at different intensities to enhance core stability and core strength. They concluded that low load core stability exercises may result in reduced LBP and injury risk (Hibbs *et al*. 2008).

Core stability exercise programs for the prevention and rehabilitation of injury should initially target segmental stabilisation to establish the basis of core stability and then integrate exercises that target both local and global muscles that are necessary to provide stability during functional movements and later during dynamic movements (Hibbs *et al.* 2008; Shankar and Chaurasia 2012; Huxel Bliven and Anderson 2013).

2.8 THE ROLE OF CORE STABILITY IN ATHLETES

All sports are different and thus different athletes require different demands. Some athletes require good balance or force production, whilst others require body symmetry. All athletes, however, require both well-developed core stability and core strength in order to stabilise the spine during dynamic movements and to improve performance (Hibbs *et al.* 2008; Hsu *et al.* 2018).

Due to the dynamic movements of the body during athletic activities, and the higher than normal loads applied during these dynamic activities, the risk of injury is greater in athletes than non-athletes (Hibbs *et al.* 2008; Prentice 2015; Wirth *et al.* 2017). Therefore, core stabilising exercise programs used in rehabilitation are not sufficient for the highly dynamic activities performed by athletes (Hibbs *et al.* 2008).

Sport coaches and fitness experts place emphasis on exercises that target and strengthen the global muscles without initially bringing attention to the local muscles that provide stability. Targeting the global muscles that are important for the specific sporting activities, can lead to muscle imbalances and inadequate ability to reduce and transfer forces where necessary (Huxel Bliven and Anderson 2013).

Vezina and Hubley-Kozey (2000) noted that insufficient strength and endurance of the core muscles and further, inappropriate recruitment of these muscles were associated with spinal instability and injuries to muscles and joints. Thus, it is important for muscle imbalances and weaknesses to be identified and corrected (Cotton 2005). Endurance of the core muscles has been identified as the most important component when training the core muscles as it contributes to spinal stability during prolonged exercise (Faries and Greenwood 2007; Barati *et al.* 2013). Therefore, placing focus on strengthening of global muscles and neglecting core stabilising exercises may result in injury to the spine and/or other joints.

2.8.1 Sport specific benefits of core stability

In swimming it is critical for the athlete to maintain posture, balance and alignment in order to produce maximum propulsion and reduce the amount of drag, yet most training programs favour strengthening exercises for arms with little focus on the core muscles (Fig 2005). Leetun *et al.* (2004) noted that 41 (28 females and 13 men) of 139 athletes (basketball and track) sustained 48 back or lower limb injuries during the season (35% of the females and 22% of the men). They observed that those athletes who sustained injuries generally had weak core muscles and therefore concluded that athletes with a weak core are at higher risk for injury (Leetun *et al.* 2004).

In overhead throwing sports, the core muscles control the transfer of the forces produced by the lower limbs, through the kinetic chain, to the throwing arm (Bliss and Teeple 2005; Khademi Kalantari and Berenji Ardestani 2013; Radwan *et al.* 2014; Silfies *et al.* 2015). The role of the core muscles varies during the different phases of the overhead throw. In the initial phases of the throw, the core muscles provide a stable base for force production (Grezios *et al.* 2006; Hilligan 2008; Silfies *et al.* 2015; Tomasa 2017). As the throw progresses, forces need to be transferred from the lower limbs to the upper limbs. During this phase the core muscles are required to reduce the forces produced by the lower limb and funnel them to the shoulder muscles of the throwing arm (Grezios *et al.* 2006; Hilligan 2008; Silfies *et al.* 2015; Tomasa 2017). It is for this reason that core stability in overhead throwing athletes is considered extremely important.

Although there have been many studies done on the exercises benefiting core stability and core strength, the research is limited and conflicting as the data collecting methods, exercise techniques and subjects used for analysis vary amongst the studies (Hibbs *et al.* 2008; Sharrock *et al.* 2011; Tomasa 2017; Hsu *et al.* 2018). No study has identified a single exercise that activates and challenges all core muscles. Therefore, it is necessary when training the core to use a combination of exercises in order to achieve core stability and strength enhancements. It is however noted that excessive training of the core can result in spinal stiffness and lead to greater spinal instability (Faries and Greenwood 2007; Hibbs *et al.* 2008).

2.9 THE ROLE OF CORE STABILITY IN WATERPOLO

Due to the nature of the game and its aquatic environment, the water polo throw is unique to other overhead throws performed on land. Although there are many similarities between water polo and most overhead throwing sports, there are however several unique and identifiable features. The most obvious difference is that the water polo athlete lacks stability as they have no stabilisation from the ground and therefore it is necessary to have a strong and stable core for the production and transfer of forces from the lower limb to the upper limbs and to maintain the water polo athletes position above the water during throwing motion (Grezios *et al.* 2006; Alexander, Hayward and Honish 2010).

In water polo, the athlete lifts his/her body out of the water in order to shoot and pass the ball or to defend the opposition by preventing them from shooting or passing (Zinner *et al.* 2015). The core muscles contract and brace the spine providing stability for the lower limbs during the breaststroke and eggbeater kicks (Alexander, Hayward and Honish 2010). The breaststroke and eggbeater kicks are used to elevate the water polo athlete’s body out of the water during throwing and defensive play. This elevated position is optimal for performance. The breaststroke kick is a synchronised movement of the legs that explosively drives the upper body upwards from the basic floating position in order to achieve maximum jumping height (Platanou 2005). Whereas, the eggbeater kick is alternating rotational movements of the legs which is used to maintain the body in an elevated position (Sanders 2005). The floating position is one in which the athlete is submerged in the water at shoulder height; small cyclical and symmetrical movements of the hands (sculling) and the eggbeater kick support the body in this position (Platanou 2005).

2.10 THE WATER POLO THROW

Many techniques are used by water polo players to throw the ball depending on their body position at the time required to shoot or pass the ball or their position in the field of play. The different types of shooting techniques used by water polo players include the penalty throw, overhead throw, push shot and back shot (Yaghoubi *et al.* 2014). The overhead throw is most commonly used as it is more accurate particularly during play (Yaghoubi *et al.* 2014). Smith (2004) reported an 80.1% success rate of penalty conversions using the overhead throw; during water polo matches in which the outcome was successful, 20% were affected by the success rate of the penalty throws.

2.11 BIOMECHANICS OF THE OVERHEAD WATER POLO THROW

The overhead throw in water polo begins with the player looking at the goals, their hips angled between 45-90 degrees towards the goals and the ball behind the player. The core muscles contract to provide stability (Alexander, Hayward and Honish 2010). The ball is picked up with the dominant hand while the weaker arm sculls to stabilise the athlete's position. The throwing shoulder is externally rotated. This is followed by an explosive breaststroke kick that elevates the player out of the water to reduce the resistance of the water and produce the force which travels through the kinetic chain to the ball (Ball 1996; Alexander, Hayward and Honish 2010). At maximum height the hips and trunk rotate towards the goals as a result of unilateral contraction of the oblique abdominals rectus abdominus, TA and multifidus muscles (Alexander, Hayward and Honish 2010; Moore, Dalley and Agur 2010). After which, the shoulder (of the throwing arm) moves forward. During this movement the shoulder is externally rotated and abducted with the elbow slightly flexed and the forearm lagging behind. The velocity of shoulder rotation is at its peak during this phase (Alexander, Hayward and Honish 2010). At ball release, bilateral contraction of the oblique abdominals rectus abdominis and TA muscles causes the trunk to flex while the elbow quickly extends and the wrist flexes as the ball leaves the athlete's hand (Alexander, Hayward and Honish 2010; Moore, Dalley and Agur 2010). During this phase, the weaker arm is brought towards the side of the body to enhance shoulder rotation. The follow through phase reduces the risk of injury to the shoulder joint as, whilst the arm crosses the body, the shoulder is internally rotated and decelerates (Ball, Comerford and Mottram 2003; Smith 2004; Alexander, Hayward and Honish 2010).

Figure 1: Water polo throw

The biomechanics of the throwing motion in water polo athletes is therefore a highly complex motion requiring co-ordination between the torso and upper and lower limbs (Ball 1996; Alexander, Hayward and Honish 2010). The core muscles facilitate the co-ordination of this complex movement (Grezios *et al.* 2006; Chu *et al.* 2016).

2.12 JUMP HEIGHT IN WATER POLO ATHLETES

Jump height in water polo is important as the greater amount of the body that the athlete is able to elevate during the throwing motion optimises the throwing ability by reducing the resistance of the water on the body and allowing optimal performance of the kinetic chain (Canossa *et al.* 2016). Research identifies that measures of vertical jump height on land are a representation of the explosive power generated by the lower limbs (Viitasalo *et al.* 1992; Abidin and Adam 2013). Platanou (2005) assessed vertical jump height on-water and dryland in water polo athletes of different competitive levels. The results identified that on-water jumping ability was greater than dryland jumping. These findings suggested that utilising the arms whilst, being supported by the water, in the jumping motion increased the height that the athlete was able to reach (Platanou 2005). However, there is no solid base for the athletes to generate force and as the mass above the water becomes greater than that below the water, there is less support offered by the water. Thus, the core muscles contract to stabilise the spine and provide a solid stable centre for the lower limb muscles to produce the power needed for the explosive breaststroke kick that elevates the water polo athlete out of the water.

2.13 THROWING VELOCITIES IN WATER POLO ATHLETES

Studies have reported throwing speeds in competitive male water polo players to range between 62.89 to 73.89 kilometres/hour (Ferragut *et al.* 2011a; Ferragut *et al.* 2011b;

Ferragut *et al.* 2015; Canossa *et al.* 2016). Numerous qualities have been identified that are thought to influence throwing velocities during the over-head throw. Ball (1996) reported that the speed of the water polo throw was a result of trunk rotation (30-35%), internal rotation or horizontal adduction of the arm (20-30%), elbow extension (20-27%), and wrist flexion (8-13%). Other studies found that upper and lower limb strength; throwing technique; vertical jumping ability and the amount of trunk flexion also contribute to the velocity (Hilligan 2008; Stodden, Campbell and Moyer 2008; Wagner *et al.* 2011; Oyama *et al.* 2014)

Research suggested that the TA, one of the vital muscles involved in providing core stability, plays a significant role in trunk flexion (Loeser 2010; Chu *et al.* 2016). Thus, greater core stability improves the ability for the athlete to elevate him/herself out of the water, increasing the potential for trunk flexion without resistance and therefore providing greater throwing velocity potential (Tomasa 2017). Therefore, training the core muscles to improve core stability and core strength may facilitate the biomechanics of the water polo throw and result in higher throwing velocities amongst water polo athletes.

2.14 CONCLUSION

Studies have outlined the role of core stability in athletes, especially in athletes involved in overhead throwing sports on land. These studies show that core stability greatly improves athletic performance (Faries and Greenwood 2007; Hibbs *et al.* 2008; Silfies *et al.* 2015; Wirth *et al.* 2017).

The core muscles play a vital role during the water polo over-head throw as the core muscles provide a stable base for the lower limbs to produce the power needed to elevate the body out of the water and transfer this force from the lower limbs through the kinetic chain and to the ball while maintaining body position. Therefore, improving core stability may improve the water polo athlete's performance with regard to jump height and throwing velocity.

This study aims to investigate the level of core stability in male water polo athletes and determine how the level of core stability may affect water polo performance in respect to jump height and throwing velocity.

CHAPTER THREE: METHODS AND MATERIALS

3.1 INTRODUCTION

This chapter describes the procedure used to conduct this study, which includes the study design, population used, sample size, recruitment process, selection criteria, measuring tools utilised and statistical analysis employed.

3.2 STUDY DESIGN

A quantitative descriptive observational study design was used to investigate the correlations between core stability, jump height and throwing velocity, in male water polo athletes (Williams 2011).

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3.3 STUDY POPULATION AND SAMPLE

The study population consisted of male water polo athletes, between the ages of 16 and 45 years of age, who participated in the Kwa-Zulu Natal (KZN) men's first division water polo league. Thus, the selected participants all exhibited the same level of skill.

At the start of this research study there was a total of 65 registered athletes. A t-test was conducted in G-POWER to determine the sample size using an alpha of 0.05, power of 0.80, a large effect size ($\rho = 0.5$) and 24 degrees of freedom. Based on the results from the t-test, the desired sample size was 26 athletes (Singh 2017).

3.4 INCLUSION AND EXCLUSION CRITERIA

3.4.1 Inclusion criteria:

Subjects were included in the study if:

1. The participant was between the ages 16-45 years old. (Parental consent was obtained for participants between the ages of 16-17 years (Appendix A and Appendix B). Participants older than 45 were not included due to arthritic changes that may occur in the hip joints post 45 as these changes may have affected the outcome of the results (Loeser 2010).
2. The participant was asymptomatic; no lower back pain was experienced for three months or longer prior to the study (Guerriero *et al.* 1999).

3. The participant was male, as anatomy and physiology differ between male and female.

3.4.2 Exclusion criteria:

Subjects were excluded from the study if:

1. The participant had contra-indications to lumbar stabilisation exercises such as: acute unstable spinal injuries; significant neurological compromise or an unstable medical condition. This was vital as he may have been adversely affected by lumbar stabilisation exercises (Standaert, Weinstein and Rumpeltes 2008).
2. The participant had a current injury that would impair his ability to throw or perform to his full potential (i.e. swimmer's shoulder, rotator cuff syndrome or thrower's elbow).
3. The participant was not actively participating in the first division water polo league whilst the study was being conducted.

3.5 STUDY SETTING

Permission was granted from the KZN First division league to conduct this study using the league members (Appendix C). This study took place at the Westville Boys High School (WBHS) swimming pool; WBHS was chosen as a data capture venue as it was one of the training facilities used by the KZN men's first division. Permission was granted by the school (Appendix D). Participation in the study took approximately 30 minutes for each participant to complete.

3.6 RECRUITMENT PROCESS

The researcher approached the participants of the KZN men's first division league. Thus, participants were recruited by word of mouth.

3.7 RESEARCH PROCEDURE:

Ethical approval was granted by the Institutional Research Ethics Committee (IREC 050/18) (Appendix I: IREC approval) at Durban University of Technology prior to commencement of the research study.

Participants interested in taking part in the study were initially questioned for eligibility. The table below outlines the questions that were used to guide the interview to establish their eligibility.

Table 4: Initial screening interview

Questions	**Desired answer**
How old are you	Between 16 and 45 years old
Which club do you play for?	Clifton, Hilton, Glenwood Old Boys 1, Glenwood Old Boys 2, Queens Park or Varsity College
Which division do you play in?	First
Do you currently have any pain in your lower back?	No
Have you experienced any low back pain in the last 3 months?	No
Do you have any injury that prevents your ability to throw?	No
To your knowledge, do you have any acute unstable spinal injuries, significant neurological compromise or an unstable medical condition?	No

Participants who were eligible and agreed to participate, were entered into the study.

Participants were given a letter of information (Appendix E) and an informed consent form (Appendix F and Appendix G) which they were required to sign in order to take part in the study.

Height and weight of each participant were measured and recorded on the data capture sheet (Appendix H).

The researcher was assisted by a research assistant during the data collection process. The role of the research assistant was to assist with the research procedures. The research assistant was a chiropractic student.

The researcher and research assistant demonstrated to the participant how to contract the core muscles. This demonstration included how to isolate the TA by performing the abdominal draw-in manoeuvre, in the four-point kneeling position (Figure 2). Participants were instructed to contract their abdominal muscles and draw their umbilicus towards their spine. This position isolates the contraction to the deep local muscles as it inhibits the global muscles (mainly the rectus abdominis) and provides a facilitated stretch to the deep abdominal muscles through the forward shift of the abdominal contents (Richardson and Jull 1995).

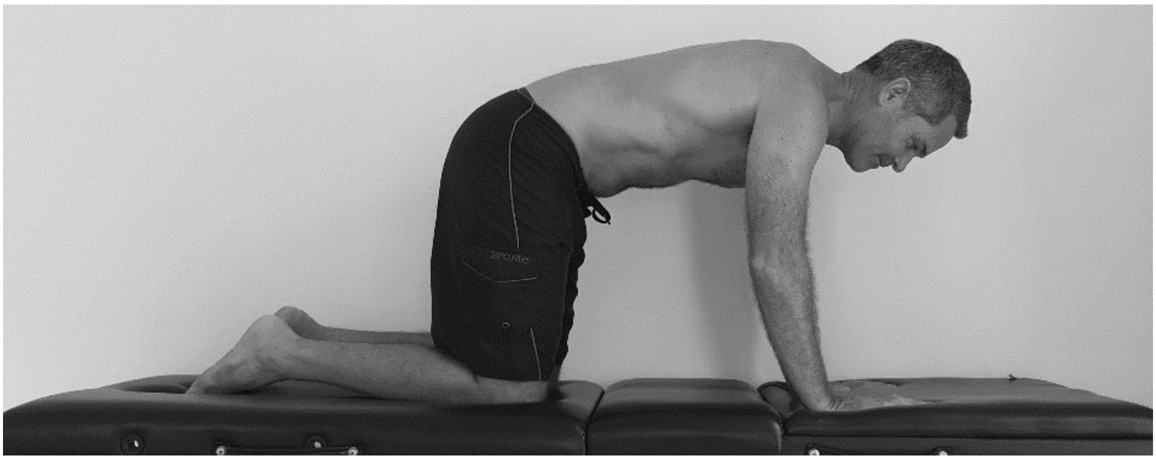

Figure 2: Abdominal hollowing in the four-point kneeling position

Once participants were able to isolate the TA correctly, they were asked to perform the Prone and Supine tests respectively.

During the Prone test (3.9.1The Prone test:), the participants were required to contract and hold their TA for a duration of four seconds, within a ten second period. This step was repeated three times whilst the researcher and research assistant observed for any compensatory movements.

The researcher and research assistant used observation and palpation to ensure contraction of the TA was performed correctly:

<u>Observation:</u>

1. Compensatory movements such as the contraction of the global abdominal musculature. Hip, pelvic, spine and shoulder girdle movement were monitored.
2. Normal, regular breathing pattern (12-24 breaths per minute).
3. Total change in pressure of the PBU.

<u>Palpation:</u>

1. Both hands placed over the TA medially and anterior to the ASIS and laterally to the rectus abdominis muscle.

After completion of the Prone test, participants performed the Supine test (3.9.2 The Supine test:). Participants were graded depending on their ability to maintain core stability, while performing different leg loading activities. The participants only continued to the next level of grading if they had successfully completed the former. Each grade was performed bilaterally.

Grade 1:

A. Single leg slide with contralateral leg supported: Test leg slides the heel down the surface of the examination table.
B. Unsupported single leg slide with contralateral leg supported: Test leg is held approximately 5cm above the examination table, then slides above the surface of the examination table.

Grade 2:

A. Single leg slide with contralateral leg unsupported: Contralateral leg is held approximately 5cm above the examination table, while the test leg slides the heel down the surface of the examination table.
B. Unsupported single leg slide with contralateral leg unsupported: Both legs held approximately 5cm above the examination table, test leg slides above the surface of the examination table.

Table 5: Level of core stability according to participant grading level

Participant grade	**Level of core stability**
1a	Poor core stability
1b	Moderate core stability
2a	Good core stability
2b	Excellent core stability

After grading of the participants' core stability was completed, participants were given time to warm up in the swimming pool.

In the pool, each participant was asked to throw the water polo ball into the goals three times using the overhead throw, during which the researcher measured throwing velocity using the speed gun. This process was recorded using a video camera. The modified yard stick was positioned in line with the camera and the participant (Figure 3) so that the participants' jump height could be measured.

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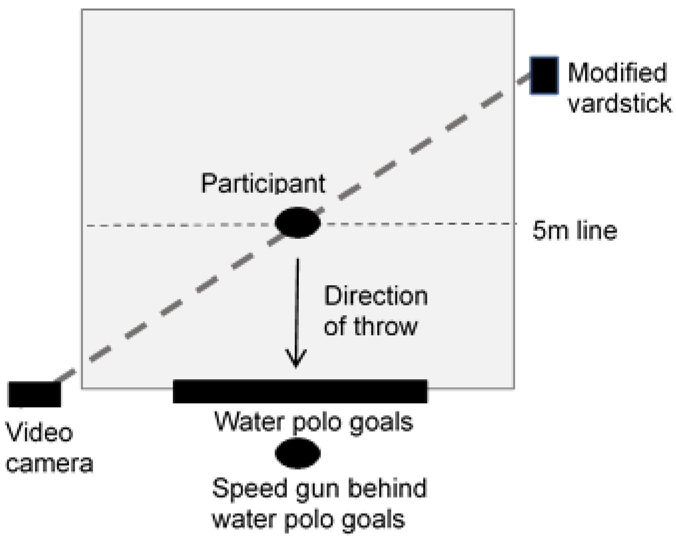

Figure 3: Set up of throwing procedure

The participants' jump height was measured from the water to the tip of the participant's head. Jump height was recorded at two points. The first point being maximum head height (max HH). This point identified the highest point reached by the participant during the throwing movement. The second point recorded was the height at which the participant released the ball (HH ball release) during the throwing movement.

An average for maximum head height, head height at ball releases and throwing velocity for the three throws was calculated and recorded on the data capture sheet (Appendix H). the measurements were later used for statistical analysis.

3.8 MEASUREMENT TOOLS

1. Pressure biofeedback unit (PBU): the PBU consists of an inelastic three section air filled bag connected to a pressure dial which monitors the pressure within the bag (Chattanooga Group, A Division of Encore Medical, 2002). It provides visual feedback of core muscle activation by monitoring the movement of a body part on or off the bag. Each movement alters the pressure within the bag and indicates muscle contraction (Richardson *et al.* 1999). Von Garnier *et al.* (2009) found a high test-retest reliability (intra-class correlation coefficient of 0.81 [95% confidence interval 0.67 to 0.90]) when using the PBU to measure TA recruitment.
2. Stopwatch: was used to time maximal muscle contraction.
3. Bushnell velocity speed gun: this measures the speed, of an object, using Doppler signal. Radio waves of a specific frequency are sent out and when a moving object

enters this transmitted signal, the reflected signal off the object is changed. Here, the change in frequency is proportional to the speed of the object. It has an accuracy of +/- 2kph. The signal transmitted has the ability to pass through materials such as plexiglass, netting, white mesh or backdrops without being affected, allowing for a protective barrier to be placed between the speed gun and the moving object without affecting the accuracy of the measurements.

4. Video camera: 1080p resolution action camera with a 60fps frame rate was used, this accurately enabled the assessment of the participants' jump height.
5. Modified yard stick: was used to measure jump height (at highest head height and height that ball was released) in relation to the water surface in centimetres.

3.9 CORE STABILITY TESTS

3.9.1 The Prone test:

The user is required to lie in the prone position with his head and neck in the neutral position and arms at his sides. The PBU is placed with the distal border at the level anterior superior iliac spine (ASIS). The PBU is inflated to 70mmHg and the user contracts the TA by performing the abdominal draw-in manoeuvre. A decrease in pressure reading of 6-10mmHg is a successful test (Richardson *et al.* 1999). Poor activation of the TA is indicated when less than a 2mmHg reduction of pressure is present, there is no change in pressure or there is an increased pressure reading. (Brotzman, Manske and Daugherty 2011).

Many studies have researched the reliability of the PRONE test to measure TA contraction. Intra-reliability varies amongst the research literature published from low reliability to excellent reliability. Costa *et al.* described the intra-reliability test with an intra-class correlation coefficient (ICC) of 0.58 [95% confidence interval (CI) 0.28 to 0.78] and Mosely reported an intra-reliability test ICC of 0.91[95% CI 0.71 to 0.99] (In von Garnier *et al.* 2009). Lastly, research conducted by von Garnier *et al.* (2009) on inter-reliability reported an ICC of 0.81 [95% CI 0.68 to 0.90].

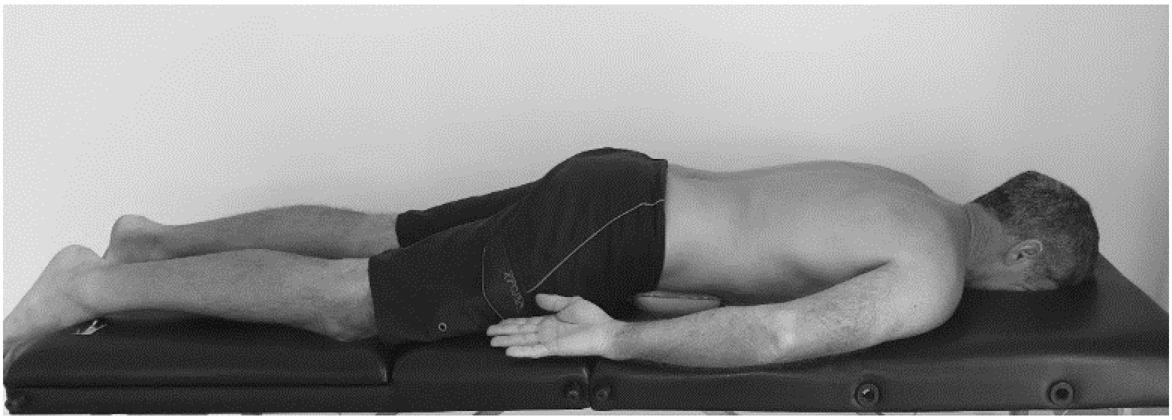

Figure 4: The PRONE test

3.9.2 The Supine test:

The user lies supine in the hook-lying position and places the PBU at the level of the posterior superior iliac spine (PSIS). The PBU is inflated to 40mmHg and the user contracts the TA and preforms various leg movements, during which, there should be no change in pressure. This test assesses one's ability to control lumbopelvic posture during various leg-loading activities (Brotzman, Manske and Daugherty 2011). Grades 1a and 1b assessed for sagittal bias as the contralateral leg supplied support during leg sliding and grades 2a and 2b assessed rotary bias as the contralateral leg was unsupported (Richardson *et al.* 1999). Kaping, Äng and Rasmussen-Barr (2015), reported a high inter-observer reliability when using the SUPINE test to evaluate core stability. However, they stated that this test was not valid when evaluating patients with low back pain (Kaping, Äng and Rasmussen-Barr 2015).

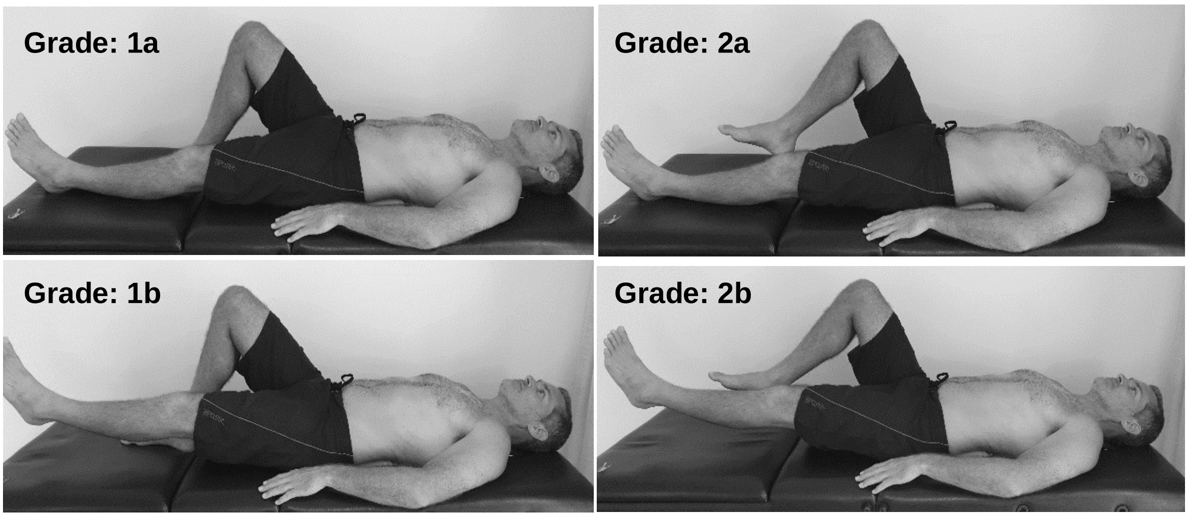

Figure 5: The SUPINE test

3.10 STATISTICAL ANALYSIS

IBM SPSS version 26 was used to analyse the data. A p-value <0.05 was considered as statistically significant. One-way ANOVA tests with Bonferroni Adjusted Post Hoc tests were used to compare mean outcomes between the three core stability groups. A p-value <0.05 was considered as statistically significant for the overall ANOVA tests. Pearson's correlations were used to assess linear relationships between throwing velocity, max HH and HH ball release.

3.11 ETHICAL CONSIDERATIONS

Approval for this study was obtained from the Institutional Research Ethics Committee at the Durban University of Technology (Appendix I: IREC approval).

All participants were required to give their consent prior to participating in this study. This included acknowledging receipt of the letter of information which adhered to the rules and regulations of autonomy.

Parental consent was required and given for participants between the ages of 16 and 17 years.

Precautions were taken to ensure that no participants were harmed when participating in this research.

The participants' identities needed to be protected, thus their names do not appear within the study or on any research documentation.

Only male water polo players were used in this study due to the difference in male and female physiology.

Only first division athletes were used, which enforced and ensured that all participants possessed a similar skill set.

CHAPTER FOUR: RESULTS

4.1 INTRODUCTION

This chapter outlines the results of data collected and analysed during this study.

4.2 DEMOGRAPHICS

Twenty-six male participants (N = 26) were selected for this study, all of whom were playing in the KwaZulu-Natal Men's First Division Water Polo League at the time that the testing occurred.

Eight participants were between the ages of 16-17. Parental consent was obtained for these eight participants. The mean age of the participants was 21 years with a range from 16 to 39 years. The mean height and weight were 183 cm and 83.5 kg respectively. The participants mean age, height and weight are tabulated below in (Table 6).

Table 6: Demographics of participants

Criteria	Valid (N)	Mean	±Standard (Std.) Deviation	Minimum	Maximum
Age (years)	26	21	6	16	39
Height (cm)	26	182	5	171	189
Weight (Kg)	26	83.5	10.8	63.7	103.2

4.3 OBJECTIVE 1: TO ASSESS CORE STABILITY IN WATER POLO ATHLETES

4.3.1 The Supine test

From the twenty-six participants, six were found to have moderate core stability, sixteen had good core stability and four had excellent core stability (Figure 6). It was noted that participants with excellent core stability were older, taller and weighed more than those participants with moderate and good core stability grades (Table 7).

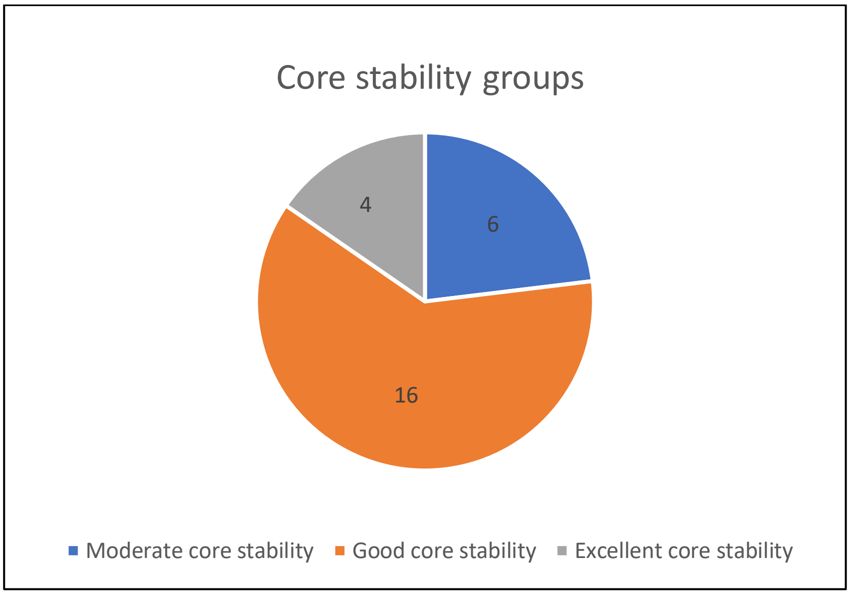

Figure 6: Distribution of participants among the three groups of core stability

Table 7: Mean age, height and weight among the three core stability groups

Descriptive						
		N	**Mean**	**±Std. Deviation**	**Minimum**	**Maximum**
Age (years)	**moderate**	6	17.50	2.739	16	23
	good	16	21.13	5.691	16	39
	excellent	4	25.75	8.016	18	37
	Total	**26**	**21.00**	**5.933**	**16**	**39**
Height (cm)	**moderate**	6	179.33	6.346	171	187
	good	16	181.13	4.759	175	189
	excellent	4	187.00	1.414	186	189
	Total	**26**	**181.62**	**5.285**	**171**	**189**
Weight (kg)	**moderate**	6	80.13	11.171	65.6	96.3
	good	16	82.43	10.122	63.7	101.9
	excellent	4	92.70	10.067	80.6	103.2
	Total	**26**	**83.48**	**10.751**	**63.7**	**103.2**

The mean age, height and weight of the participants were compared among the three groups of core stability using the overall one-way ANOVA test (Table 8). There was a non-statistically significant overall difference for the three groups of core stability regarding the participants' age, height and weight (p=0.093, p=0.061 and p=160 respectively).

Table 8: Overall one-way ANOVA test to compare mean age, height and weight among the three core stability groups

ANOVA						
		Sum of Squares	**Df**	**Mean Square**	**F**	**Significance level (Sig).**
Age (years)	**Among Groups**	164.000	2	82.000	2.634	0.093
	Within Groups	716.000	23	31.130		
	Total	**880.000**	**25**			
Height (cm)	**Among Groups**	151.071	2	75.535	3.176	0.061
	Within Groups	547.083	23	23.786		
	Total	**698.154**	**25**			
Weight (kg)	**Among Groups**	425.043	2	212.521	1.983	0.160
	Within Groups	2464.783	23	107.164		
	Total	**2889.826**	**25**			

4.3.2 The Prone test

The mean change in pressure and time of sustained contraction, for the PRONE test, ranged from 8.78mmHg to 12.33mmHg and 8.28s to 9.92s respectively. The overall one-way ANOVA test demonstrated a high level of significance for the three core stability groups in terms of change in pressure (p=0.001) and time (p=0.001) (Table 10).

Table 9: Mean change in pressure and average time of sustained core contraction among the three core stability groups

Descriptive						
		N	**Mean**	**±Std. Deviation**	**Minimum**	**Maximum**
Average change in pressure (mmHg)	**Moderate**	6	8.78	0.78	7.67	9.67
	Good	16	10.25	1.05	8.67	12.00
	Excellent	4	12.33	0.27	12.00	12.67
	Total	**26**	**10.23**	**1.42**	**7.67**	**12.67**
Average time (seconds)	**Moderate**	6	8.28	0.80	7.33	9.33
	Good	16	9.48	0.67	7.67	10.00
	Excellent	4	9.92	0.17	9.67	10.00
	Total	**26**	**9.27**	**0.85**	**7.33**	**10.00**

Table 10: Overall one-way ANOVA test to compare average change in pressure and average time of sustained core contraction among the three core stability groups

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Average change in pressure (mmHg)	**Among Groups**	30.356	2	15.178	17.618	<0.001
	Within Groups	19.815	23	0.862		
	Total	**50.171**	**25**			
Average time (seconds)	**Among Groups**	8.280	2	4.140	9.573	0.001
	Within Groups	9.947	23	0.432		
	Total	**18.226**	**25**			

4.3.3 Conclusion for objective 1

There was a distinct correlation among excellent core stability and age, height and weight. Furthermore, athletes with excellent core stability were able to maintain their core contraction for longer periods of time.

4.4 OBJECTIVE 2: TO MEASURE JUMP HEIGHT AND THROWING VELOCITY IN WATER POLO ATHLETES

The mean values for jump height were calculated at maximum head height (64.22 cm) and head height at ball release (59.50 cm). The speeds recorded for throwing velocity ranged from 50.33 km/h to 77.33 km/h with a mean of 63.35 km/h. Over all faster throwing velocities (71.75 km/h), greater maximum head height (75.58 cm) and higher head height at ball release (72.75 cm) were found in participants with excellent core stability (Table 11).

Table 11: Maximum head height, head height at ball release and throwing velocity for the three core stability groups

Descriptive						
		N	**Mean**	**±Std. Deviation**	**Minimum**	**Maximum**
Max HH (cm)	**moderate**	6	57.67	9.262	41.00	69.33
	Good	16	63.83	10.246	46.00	79.67
	excellent	4	75.58	7.475	65.00	81.33
	Total	**26**	**64.22**	**10.859**	**41.00**	**81.33**
HH ball release (cm)	**moderate**	6	53.50	9.586	40.00	66.00
	Good	16	58.44	10.893	42.00	78.00
	excellent	4	72.75	8.261	62.00	81.00
	Total	**26**	**59.50**	**11.628**	**40.00**	**81.00**
Throwing velocity (km/h)	**moderate**	6	56.78	5.115	50.33	62.33
	Good	16	63.71	5.936	52.67	76.33
	excellent	4	71.75	5.534	64.67	77.33
	Total	**26**	**63.35**	**7.197**	**50.33**	**77.33**

4.4.1 Graphic representation of throwing velocity, maximum head height and head height at ball release for the three core stability groups

When the information was analysed using graphs, a linear trend was observed for all three outcomes which showed that as core stability increased so did maximum head height, head height at ball release and throwing velocity (Figure 7 Figure 8 and Figure 9).

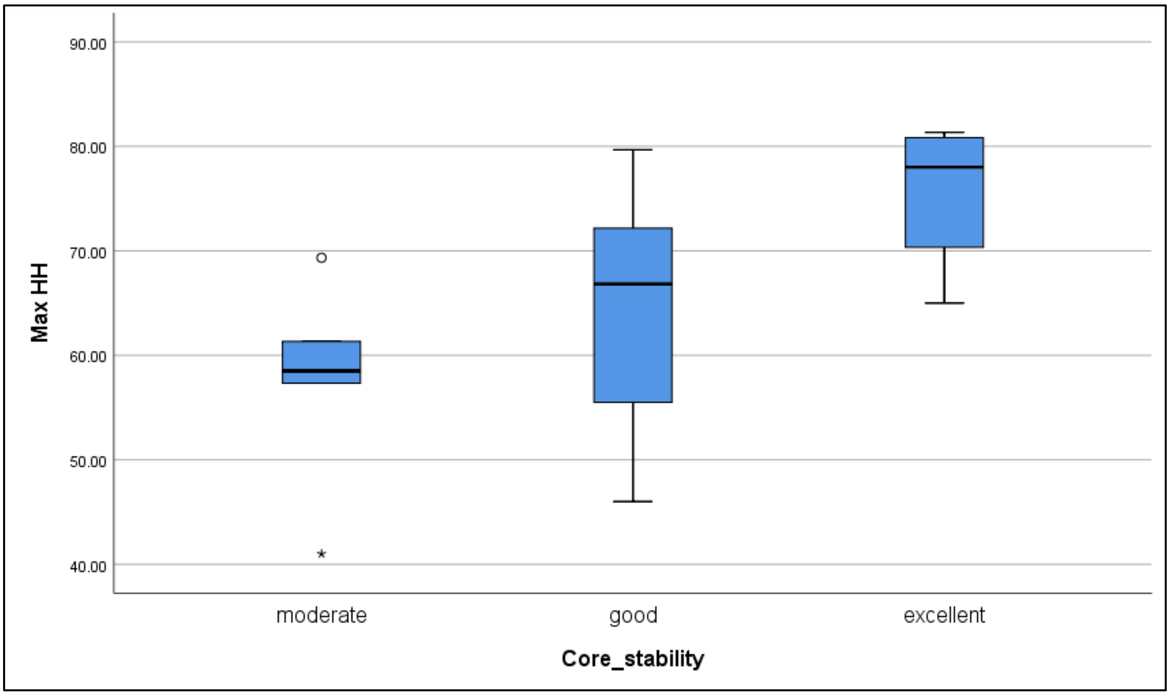

Figure 7: Box and whisker plots of maximum head height among the three groups of core stability

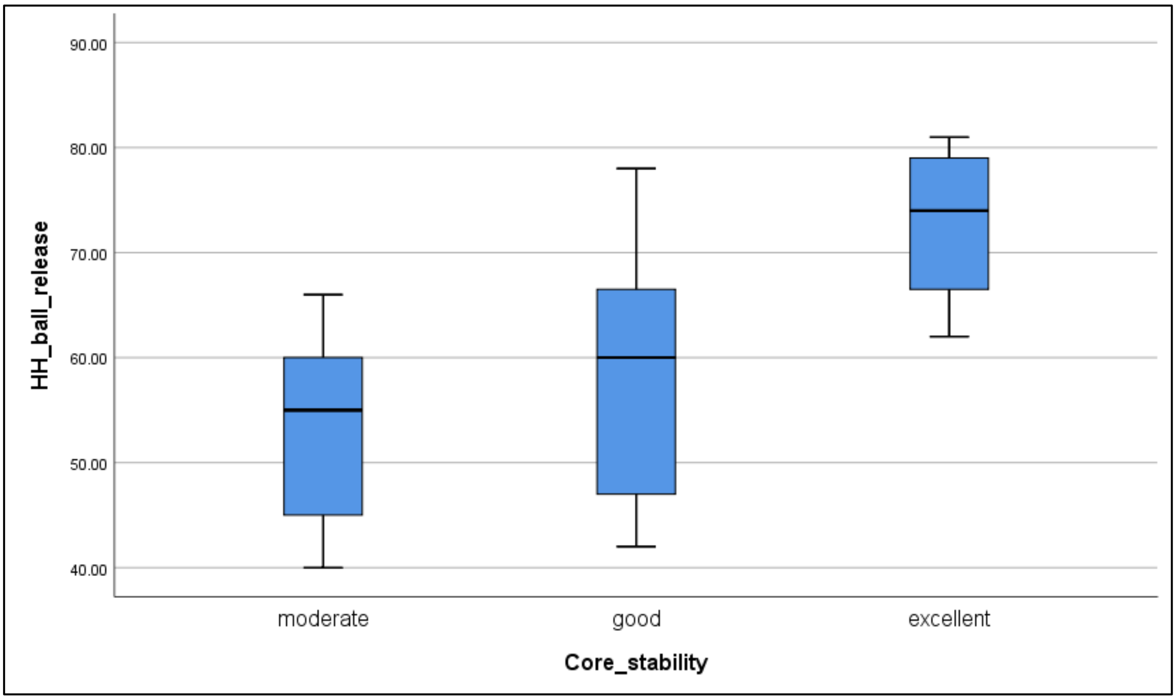

Figure 8: Box and whisker plots of head height at ball release among the three groups of core stability

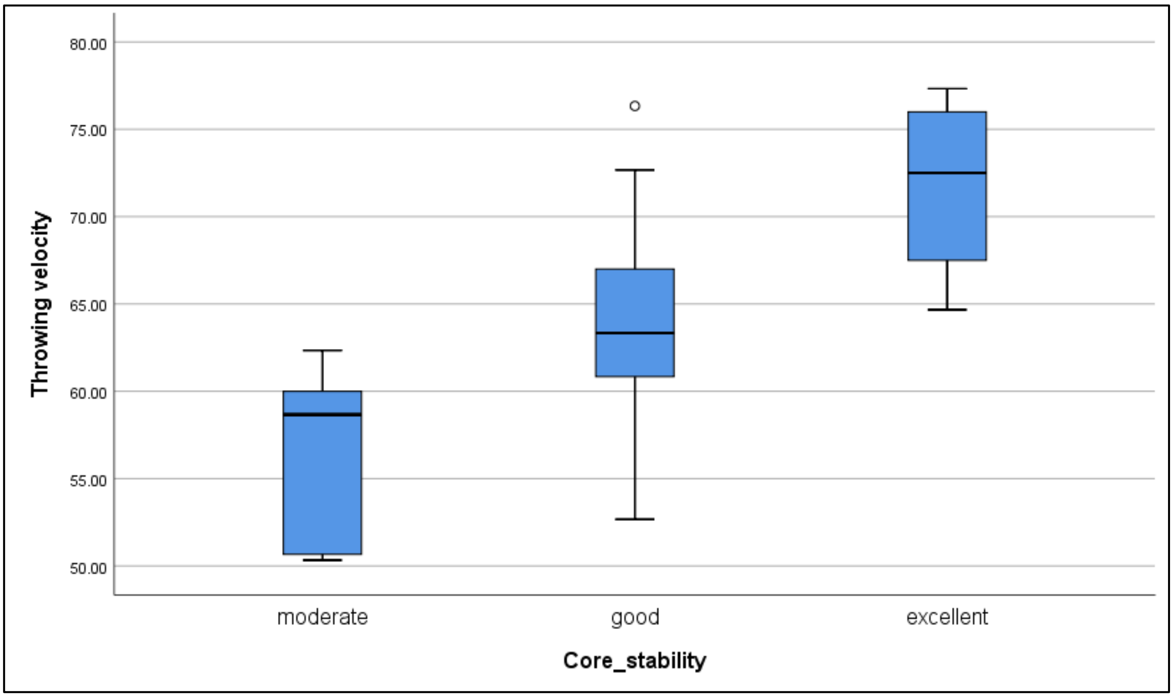

Figure 9: Box and whisker plots of throwing velocity among the three groups of core stability

The overall one-way ANOVA test was used to compare the means among the three core stability groups (Table 12). For each of the three outcome measures, there was a statistically significant overall difference among the three groups of core stability. This showed that as core stability improved, so did the participants' maximum head height, head height at ball release and throwing velocity (p= 0.030 for maximum head height, p=0.024 for head height at ball release and p=0.002 for throwing velocity).

Table 12: Overall one-way ANOVA test to compare means of the outcomes among the three core stability groups

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Max HH (cm)	**Among Groups**	776.571	2	388.285	4.113	0.030
	Within Groups	2171.194	23	94.400		
	Total	**2947.765**	**25**			
HH ball release (cm)	**Among Groups**	936.313	2	468.156	4.405	0.024
	Within Groups	2444.188	23	106.269		
	Total	**3380.500**	**25**			
Throwing velocity (km/h)	**Among Groups**	543.459	2	271.729	8.318	0.002
	Within Groups	751.315	23	32.666		
	Total	1294.774	25			

4.4.2 Conclusion for objective 2

Participants who had excellent core stability had greater maximum head height greater head height at ball release and faster throwing velocities compared to participants with moderate and good core stability.

4.5 OBJECTIVE 3: TO ESTABLISH A CORRELATION AMONG CORE STABILITY, JUMP HEIGHT AND THROWING VELOCITY IN WATER POLO ATHLETES

Having established overall statistical significance, the individual group differences were investigated using Bonferroni Adjusted Post Hoc tests. In all cases it was the moderate and excellent core stability groups which differed the most from each other.

Maximum head height reached a level of significance between the moderate and excellent core stability groups (p=0.027), while the difference between good and moderate and good and excellent core stability groups did not reach statistical significance. This demonstrated that participants with excellent core stability were able to reach a significantly higher maximum head height when jumping during the throwing motion than participants with moderate and good core stability.

Head height at ball release reached a level of significance between the moderate and excellent core stability groups (p=0.025), while the difference between good and moderate and good and excellent core stability did not reach statistical significance. This demonstrated that participants with excellent core stability were able to reach a significantly higher maximum head height when jumping during the throwing motion than participants with moderate and good core stability.

Throwing velocity reached statistical significance for all three groups of core stability with statistical significance between moderate and good core stability, moderate and excellent core stability and good and excellent core stability being p=0.056; p=0.001 and p=0.058 respectively (Table 13). This demonstrated that participants with excellent core stability were able to throw significantly faster than participants with moderate and good core stability.

Table 13: Comparisons of the outcomes among the three core stability groups

Multiple Comparisons					
Bonferroni					
Dependent Variable	**(I) Core stability**	**(J) Core stability**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
Max HH (cm)	**Moderate**	**Good**	-6.16667	4.65116	0.594
		Excellent	-17.91667*	6.27162	0.027
	Good	**Moderate**	6.16667	4.65116	0.594
		Excellent	-11.75	5.43138	0.123
	excellent	**Moderate**	17.91667*	6.27162	0.027
		Good	11.75	5.43138	0.123
HH ball release (cm)	**moderate**	**Good**	-4.9375	4.93491	0.982
		Excellent	-19.25000*	6.65423	0.025
	Good	**Moderate**	4.9375	4.93491	0.982
		Excellent	-14.3125	5.76273	0.062
	excellent	**Moderate**	19.25000*	6.65423	0.025
		Good	14.3125	5.76273	0.062
Throwing velocity (km/h)	**Moderate**	**Good**	-6.93056	2.73604	0.056
		Excellent	-14.97222*	3.68928	0.001
	Good	**Moderate**	6.93056	2.73604	0.056
		Excellent	-8.04167	3.19501	0.058
	Excellent	**Moderate**	14.97222*	3.68928	0.001
		Good	8.04167	3.19501	0.058
***. The mean difference is significant at the 0.05 level.**					

4.5.1 Correlations among outcomes

Pearson correlation was used to identify correlations among maximum head height, head height at ball release and throwing velocity. The results revealed that there was a moderately strong positive linear relationship between all three of the outcome measures (Figure 10, Figure 11 and Figure 12). Thus, improvement of one outcome was related to improvement of the other two outcomes. The strongest relationship was between maximum head height and head height at ball release (r = 0.945): this represented a very strong linear relationship.

Table 14: Correlations among the outcomes

Correlations				
		Max HH	**HH ball release**	**Throwing velocity**
Max HH (cm)	**Pearson Correlation**	1	0.945**	0.613**
	Sig. (2-tailed)		0.000	0.001
	N	26	26	26
HH ball release (cm)	**Pearson Correlation**	0.945**	1	0.616**
	Sig. (2-tailed)	0.000		0.001
	N	26	26	26
Throwing velocity (km/h)	**Pearson Correlation**	0.613**	0.616**	1
	Sig. (2-tailed)	0.001	0.001	
	N	26	26	26
****. Correlation is significant at the 0.01 level (2-tailed).**				

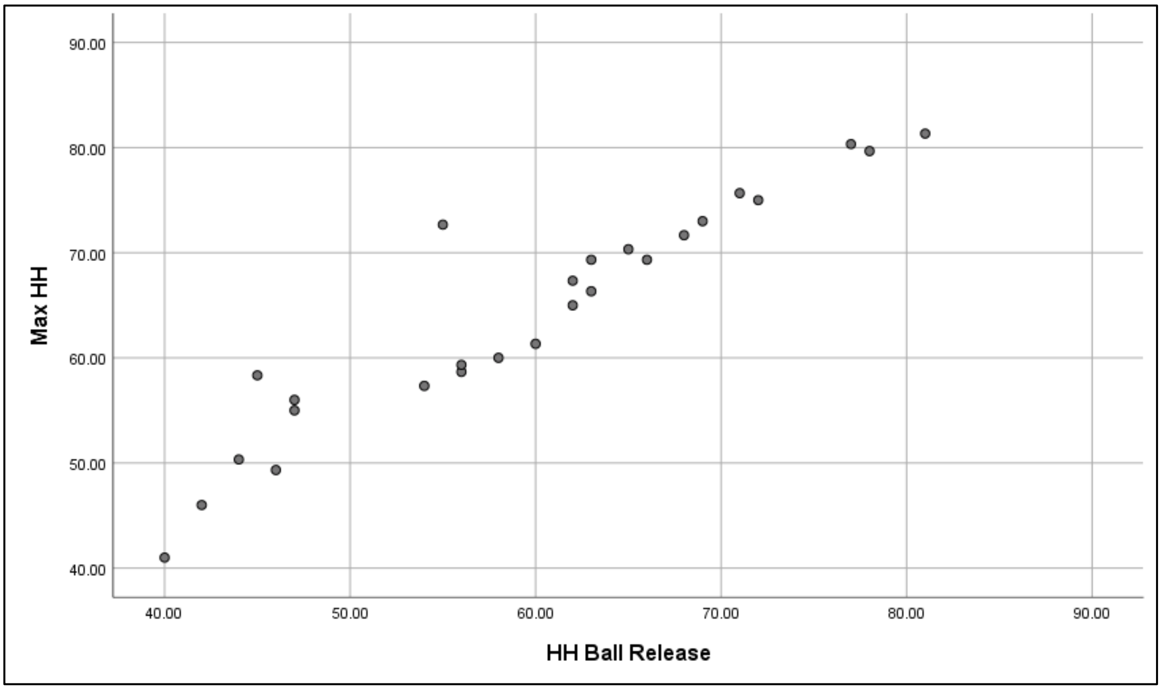

Figure 10: Scatter plot of maximum head height and head height at ball release

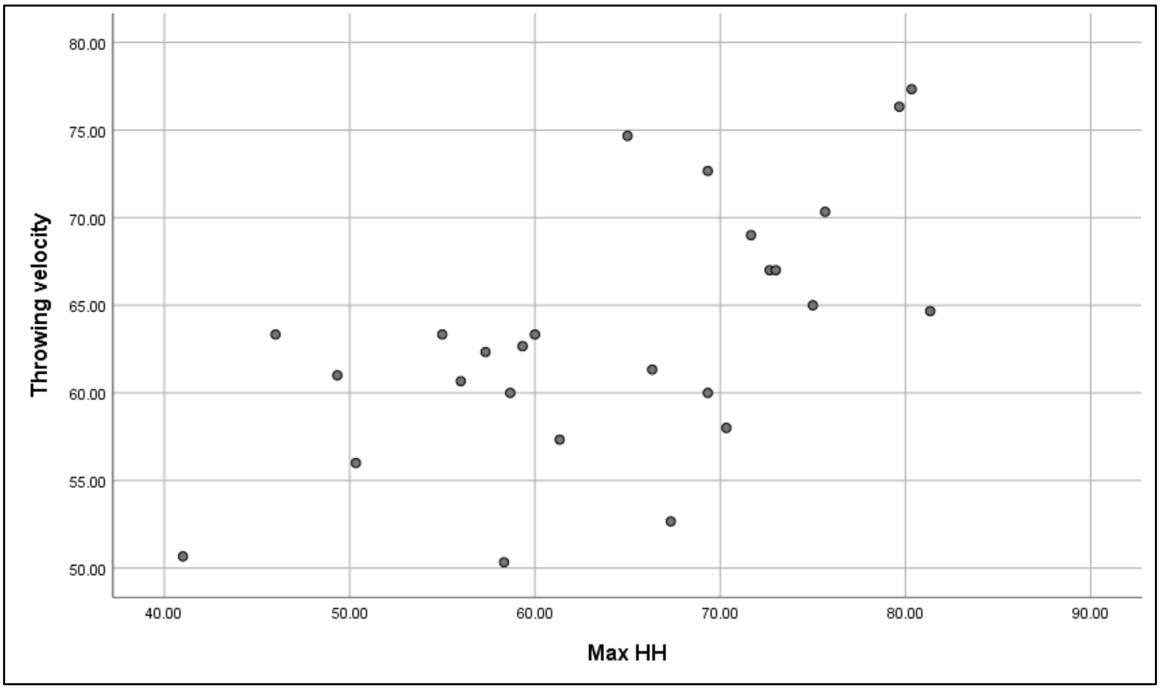

Figure 11: Scatter plot of throwing velocity and maximum head height

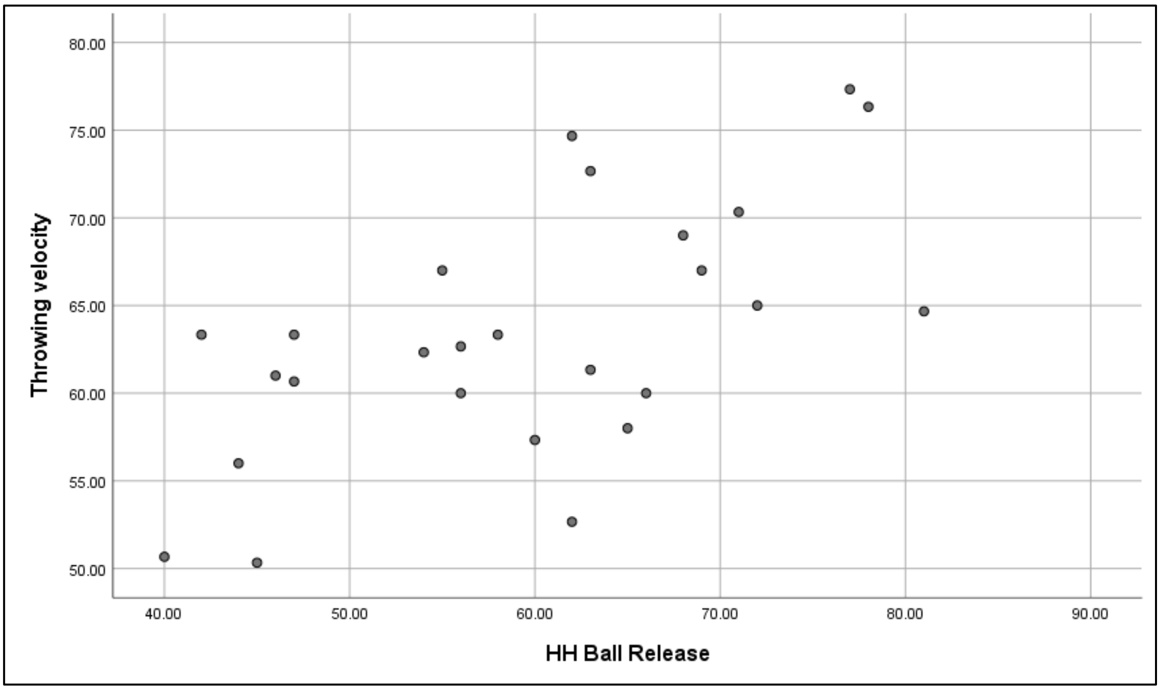

Figure 12: Scatter plot of throwing velocity and head height at ball release

4.5.2 Conclusion for objective 3

Correlations were seen between core stability and all three outcome measures, with the greatest increase in outcome being between the moderate and excellent core stability groups. Correlations were also drawn among the three outcome measures with the most significant difference being between maximum head height and head height at ball release.

CHAPTER FIVE: DISCUSSION

5.1 INTRODUCTION

The aim of this study was to determine the role of core stability in water polo athletes by identifying if a relationship among core stability, jump height and throwing velocity exists in male water polo players. This chapter discusses the results found during this study.

5.2 DISCUSSION OF RESULTS FOR THE DEMOGRAPHICS

The mean age (21 years) of the participants for this study was younger than the mean age (22-26 years) of elite water polo athletes of other studies (Platanou 2005; Vila *et al.* 2009; Ferragut *et al.* 2011a; Ferragut *et al.* 2011b; Canossa *et al.* 2016). However the mean height (182 cm) and weight (83.5 kg) of the participants in this study corresponded to the mean height (179-188 cm) and weight (75-91 kg) of athletes in other water polo based studies (Platanou 2005; Vila *et al.* 2009; Ferragut *et al.* 2011a; Ferragut *et al.* 2011b; Canossa *et al.* 2016). Therefore, the sample characteristics of this study were comparable to other studies based on water polo athletes.

5.3 DISCUSSION OF RESULTS FOR OBJECTIVE 1: TO ASSESS CORE STABILITY IN WATER POLO ATHLETES

There was an inconsistent number of participants in each group after their level of core stability was graded. This may have skewed the results or may have made comparison between the groups based on core stability difficult. However, because the age, height and weight of the participants in this study did not reach statistical significance, the groups of core stability were comparable to one another.

5.3.1 The Supine test

This study found that participants who were graded with excellent core stability had a higher mean age (25.75 years) and height (181.62 cm) compared to participants who were graded with moderate and good core stability (Age: 17.50 and 21.13 years; Height: 179.33 and 181.13 cm respectively).

The average age of physical maturity in males is 16-18 years of age and but some males may only reach maturity in their early 20’s (Tanner and Davies 1986; Grummer-Strawn, Reinold and Krebs 2011). Studies have shown that performance of athletic properties such as balance and muscular strength/power increase as males reach maturity (Muehlbauer, Gollhofer and Granacher 2015; Hammami *et al.* 2016). Therefore, athletes who have a higher age are physically more mature which could allow for greater control of muscular contraction. This could explain why athletes who were older were graded with higher levels of core stability as their core muscle were more developed and therefore, they were able to recruit their lumbar-sacral muscles and TA more effectively.

The mean weight for participants with excellent core stability was 92.70 kg compared to the mean weight of the participants with moderate and good core stability grades; 80.13kg and 82.43 kg respectively. Because muscle tissue is denser than fat tissue, muscle weighs more than fat (Tortora and Derrickson 2008; Moore, Dalley and Agur 2010). Although the body mass index (BMI) and percentage of muscle mass was not measured and calculated in this study, it is still suggested that the participants with excellent core stability may have had greater muscle mass then the participants with moderate and good core stability. Greater muscle mass provides greater contractile ability and in addition, core muscle endurance enables them to be more effective when controlling lumbopelvic posture during the various leg loading activities (Huxel Bliven and Anderson 2013).

5.3.2 The Prone test

Richardson *et al.* (1999) proposed that a reduction of pressure 6-10mmHG during the Prone test indicated a successful test. However, the mean values taken during this study (8.78mmHg – 12.33mmHg) are not within the readings that Richardson *et al.* (1999) proposed. An explanation may be that the participants in the study done by Richardson *et al.* (1999) were not athletes and muscle mass may have been different. But these pressure readings recorded were similar to more recent studies done on athletes by Robertson (2005), Martin (2006), Ferguson (2007) and Hilligan (2008) who recorded mean pressure readings of 13.00mmHg – 13.08mmHg, 10.96mmHg – 13.15mmHg, 10.9mmHg and 10.93mmHg – 14.67mmHg respectively. In the studies mentioned, the athletes were of similar age, height and weight ranges to the athletes used in this study. Therefore, the participants used in this study can be compared to the participants used in the studies mentioned above.

Jull *et al.* (1993) reported that the TA and oblique abdominals do not always activate optimally in asymptomatic individuals and that they may even fatigue during their role in stabilising the spine. This study found that the participants who had excellent core stability were able to maintain core muscle contraction for longer periods of time (9.92s) compared to participants with moderate and good core stability (8.28s and 9.48s respectively). This suggests that participants with excellent core stability were able to recruit their core muscles more optimally than participants with good and moderate core stability (Vezina and Hubley-Kozey 2000). Furthermore, participants with excellent core stability had greater core muscle endurance enabling them to maintain core stability more effectively during prolonged exercise (Faries and Greenwood 2007; Barati *et al.* 2013).

5.4 DISCUSSION OF RESULTS FOR OBJECTIVE 2: TO MEASURE JUMP HEIGHT AND THROWING VELOCITY IN WATER POLO ATHLETES

Sport-specific skills are commonly measured to evaluate the potential for athletic performance during specific sports (Sharrock *et al.* 2011). This study focused on jumping ability and throwing velocity as performance predictors as both skills are necessary during offense and defence in water polo.

Jump height is important in water polo as it allows for more effective throwing (Canossa *et al.* 2016). Jump height was recorded at two points: maximum head height and head height at ball release. The mean maximum head height and head height at ball release were 64.22cm and 61.33cm respectively. These recordings were within the readings recorded by Platanou (2005) (56.5-79.5 cm). However, the readings in this study were in fact higher as jump height in this study was recorded from the water to the tip of the participant's head whereas Platanou (2005) measured jump height from the surface of the water to the participant's finger tips. A possible reason for participants in this study being able to reach greater jumping heights may be because the participants in this study weighed less (83.5 kg) than the participants in the study done by Platanou (2005) (88.5 kg) and therefore, the participants in this study had less weight to expel out of the water allowing them to reach greater heights. Davis *et al.* (2003) reported that body fat percentage has a negative effect on jump height in athletes. Therefore, lighter athletes have greater jumping potential then athletes of the same height but weigh more.

High throwing velocities are reported as being an essential component in the overhead water polo throw, as this skill is utilised when scoring a goal. Higher jumping ability improves throwing ability and therefore improves throwing velocities (Canossa *et al.* 2016). This study recorded speeds of 50.33 to 77.33 kilometres/hour, which is relative to mean throwing velocities recorded by other competitive male water polo athletes: 62.89 to 73.89 kilometres/hour (Ferragut *et al.* 2011a; Ferragut *et al.* 2011b; Canossa *et al.* 2016). The greater range in throwing velocities recorded in this study compared to other studies that recorded throwing velocities in water polo athletes may be due to the variety of core stability grades measured in this study. Higher levels of core stability promote optimum functioning of the kinetic chain and allow forces to be transferred more effectively to the throwing arm and ball resulting in faster throwing velocities (Khademi Kalantari and Berenji Ardestani 2013; Radwan *et al.* 2014; Silfies *et al.* 2015). Therefore, when the core muscles do not stabilize the spine effectively, force production and transfer is suboptimal and results in reduced throwing velocities.

5.4.1 Jump height and throwing velocity comparison among the three groups of core stability

There was a statistically significant difference among maximum head height (p=0.030), head height at ball release (p=0.24) and throwing velocity for all three core stability groups. This suggests that improving core stability in water polo athletes significantly improves performance as it optimises the functioning of the kinetic chain during open kinetic chain exercises (Hibbs *et al.* 2008; Okada, Huxel and Nesser 2011; Wirth *et al.* 2017).

5.4.2 Jump height and throwing velocity comparison among the demographics

In this study, higher vertical jumping ability and faster throwing velocities were recorded in athletes with excellent core stability (Figure 7, Figure 8 and Figure 9). These athletes had a higher age range, were taller and weighed more (Table 7). Higher age may be related to participants' level of experience, as other studies identified that participants who had more experience were able to jump higher and throw faster than those who had less experience (Platanou 2005; Ferragut *et al.* 2011b). Participants who weighed more had faster throwing speeds. The higher weight could be due to greater muscle mass, enabling the participants to generate more power during the throwing motion resulting in higher vertical jumping abilities and throwing velocities (Ferragut *et al.* 2011a).

5.5 DISCUSSION OF RESULTS FOR OBJECTIVE 3: TO ESTABLISH A CORRELATION BETWEEN CORE STABILITY, THROWING VELOCITY AND JUMP HEIGHT IN WATER POLO ATHLETES

This study showed that participants with excellent core stability had both greater vertical jumping ability and greater throwing velocities when shooting compared to participants with moderate core stability (Table 13). These results acknowledge that the core muscles play a vital role in athletic performance as both vertical jumping ability and throwing are important skills for water polo athletes to have. Jumping ability and throwing are skills necessary for scoring goals and defending the opposition and are therefore a measure of the water polo athlete's performance. Activating the core muscles provides a steady centre for movement of the limbs. By doing so the lower limbs are able to produce the power for the breaststroke kick that elevates the water polo athlete out of the water and allows the force to be transferred through the kinetic chain to the throwing arm and lastly, the ball (Bliss and Teeple 2005; Silfies *et al.* 2015; Tomasa 2017).

There was a significant relationship between: core stability and maximum head height (p=0.027), core stability and head height at ball release (p=0.025) and core stability and throwing velocity (p=0.001) (Table 13). This suggests that core stability has a direct influence on water polo performance as there was a significant improvement in the performance outcomes between moderate and excellent core stability groups (Sharrock *et al.* 2011).

5.5.1 Correlations among core stability, jump height and throwing velocity

Statistically significant correlations were found among maximum head height and throwing velocity (r = 0.613), maximum head height and head height at ball release (r = 0.945) and head height at ball release throwing velocity (r = 0.616) revealing the higher the athlete was able to elevate themselves and release the ball, the greater the velocity of the thrown ball (Table 14).

The results from this study suggest that the core stability has a vital role in vertical jumping ability. Despite all participants being of the same competitive level, participants with excellent core stability showed a greater vertical jumping ability. This proposes that athletes with excellent core stability had better control of their core muscles optimising their power output and maintaining their body position during the throwing motion. Vertical jumping ability, during the water polo throw, is advantageous as air offers less resistance than water, permitting greater acceleration.

Previous research suggests that with greater core stability, there is greater control of the lumbar spine in the neutral zone, reducing the amount of lateral movement and enabling forces to be transferred through the body in a straight line, enhancing the throwing ability (Hedrick 2000). With more of the body out of the water, less support is offered by the water and the athlete relies on the core muscles for support. The results for this study are in conflict with the results by (Platanou 2005) who compared jump height on land versus water between water polo athletes of different competitive levels and suggested that the vertical jumping ability seen in water polo athletes is due to the continuous support of the water and the use of the arms during the jumping motion. However, Platanou (2005) did not take core stability into consideration which may have been overlooked.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

It was initially hypothesised that water polo athletes with a more stable core would be able to jump higher and throw faster, thereby optimising their performance and reducing their risk of injury. The results of this study support this hypothesis demonstrating a significant relationship between core stability and jump height (for maximum head height $p = 0.027$ and head height at ball release $p = 0.025$), and core stability and throwing velocity ($p = 0.001$).

Therefore, the hypothesis for this study was accepted and the null-hypothesis was rejected.

The information obtained by the results of this study may be beneficial to coaches and health care professionals working with water polo athletes.

6.2 LIMITATIONS

1. Core stability had to be measured on land as there was no available test to measure core stability in water.
2. Environmental factors such as air temperature and weather conditions may have impacted the results of the study as, throwing velocity was measured in an outdoor pool.

6.3 RECOMMENDATIONS

While this study observed the relationship between core stability, throwing velocity and jump height, further investigations are needed to determine the exact role of the core in water polo athletes. The following recommendations are suggested for future research in this field:

1. A larger sample size spanning a wider range of competitive levels may yield different results.
2. A similar study using female water polo athletes would identify and determine any gender differences.
3. It is suggested that similar studies be conducted using an indoor arena to eliminate environmental variables.

4. It is recommended that additional tests be done and used in conjunction with the Prone and Supine tests to determine the level of core stability.
5. Core stability, core strength, upper and lower limb strength, and limb length should be assessed to determine their relationship to throwing velocities and jump height in water polo athletes.

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Appendix A: Parent/ Legal guardian letter of information

LETTER OF INFORMATION:

Dear Parent or Legal Guardian.

I'm a Chiropractic Masters student at Durban University of Technology and I'm currently doing my dissertation. May I ask your permission for your son to participate in my research.

Title of the Research Study: The effect of core stability on male water polo players' jump height and throwing velocity.

Principal Investigator/s/researcher: Nicole McKenzie (B.Tech: Chiropractic)

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

Brief Introduction and Purpose of the Study: Core stability has been studied thoroughly and is known to be an important factor in overhead throwing athletes, as the limbs are unable to function optimally without a strong and stable core. However, there is no literature on the role of core stability when ground reactive forces are removed. This research aims to identify the relationship between core stability, jump height and throwing velocity.

Outline of the Procedures: Research will take place at Westville Boys High School. 26 participants will be required to undergo two tests to assess core stability and then throw the water polo ball into the goals as fast as possible. A video camera will be used to assess jump height and the speed of each shot will be measured using a speed radar gun. The process is expected to last no longer than 30 minutes per participant,

Risks or Discomforts to the Participant: No adverse effects are anticipated from this research

Benefits: This study will help increase all health care professional's knowledge in the treatment and rehabilitation program, helping athletes return to their optimal functioning level.

Commitment to the Study: Participants may withdraw from the study at any point for any reason without consequences.

Remuneration: There will be no remuneration offered.
Costs of the Study: There will be no cost involved in this study.

Confidentiality: Your child's information will be kept confidential and will be store at Durban University of Technology's Chiropractic department in a safe for five years. Thereafter it will be destroyed by a shredding machine.

Research-related Injury: Your child will not be injured during this research study.

Persons to Contact in the Event of Any Problems or Queries: Please contact the researcher, Nicole McKenzie (tel no: 0810437314), my supervisor, Dr Grant Matkovich (tel no: 0312018204) or the Institutional Research Ethics Administrator on 031 373 2375. Complaints can be reported to the Director: Research and Postgraduate Support, Prof Napier on 031 373 2326 or carinn@dut.ac

Appendix B: Consent form for Parent/ Legal guardian

CONSENT:

Parent/ legal guardian

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Nicole McKenzie, about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: IREC 050/18.
- 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 the sex, age, date of birth, initials and diagnosis of my son 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 computerized system by the researcher.
- Your son may, at any stage, without prejudice, withdraw his consent and participation in the study.
- I have had sufficient opportunity to ask questions and declare my son prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my son's participation will be made available to me.

______________________	________	______________
Full Name of Participant	**Date**	**Signature**

______________________	________	______________
Full Name of parent/ legal guardian	**Date**	**Signature**

(if under the age of 18)

I, Nicole McKenzie, herewith confirm that the above participant and legal guardian have been fully informed about the nature, conduct and risks of the above study.

______________________	________	______________
Full Name of Researcher	**Date**	**Signature**

______________________	________	______________
Full Name of Witness	**Date**	**Signature**

Appendix C: Gate keeper's permission – KZN water polo

To the Master in Charge of KZN Water Polo

My name is Nicole McKenzie. I am a 6th year chiropractic student at the Durban University of Technology (DUT). I would like to request permission to conduct my research study on your premises.

Title of the Research Study: The effect of core stability on male water polo players' jump height and throwing velocity.

Supervisor: Grant Matkovich (M.Tech Chiropractic)
Student: Nicole McKenzie (B.Tech: Chiropractic)

Participants from the men's first division water polo league will be recruited to participate in this research study. Research will be conducted on nights of league fixtures. The study requires the use of a swimming pool. Participants will be given a letter of information and informed consent.

This research will pose no threat to the school nor the participant. No risk or discomfort is anticipated in this research.

With your permission, the research will take place at Westville Boys High School. A sample size of 26 male water polo players. Core stability will be assessed on land and throwing velocity and jump height will be assessed in the pool. The process is expected to last no longer than 30 minutes per participant,

The dissertation is the final part of me obtaining my MTech: Chiropractic degree. Permission from you is required for me to utilize the swimming pool to conduct this research.

Your assistance would be highly appreciated and is vital to this research.

Attached is a letter of consent. Please read and sign accordingly.

Kind Regards
Ms N. McKenzie (B.Tech Chiropractic)
Researcher

LETTER OF CONSENT

- I hereby confirm that I have been informed by the researcher, Nicole McKenzie, about the nature, conduct, benefits and risks of this research
- I have also received, read and understood the above written information regarding this research
- I have had sufficient opportunity to ask questions and (of my own free will) hereby grant permission to use Westville Boy's High school as a venue.
- I understand that a copy of the end results of this research will be made available to me at my request

______________________	__________	____________________
Full Name of MIC	**Date**	**Signature**

I, Nicole McKenzie hereby confirm that the Principal has been fully informed about the nature, conduct and risks of this research.

______________________	__________	____________________
Full Name of Researcher	**Date**	**Signature**

______________________	__________	____________________
Full Name of Supervisor	**Date**	**Signature**

Appendix D: Gate keeper's permission – WBHS

To the Principal of Westville Boy's High school

My name is Nicole McKenzie. I am a 6th year chiropractic student at the Durban University of Technology (DUT). I would like to request permission to conduct my research study on your premises.

Title of the Research Study: The effect of core stability on male water polo players' jump height and throwing velocity.

Supervisor: Grant Matkovich (M.Tech Chiropractic)
Student: Nicole McKenzie (B.Tech: Chiropractic)

Participants from the men's first division water polo league will be recruited to participate in this research study. Research will be conducted on nights of league fixtures. The study requires the use of a swimming pool. Participants will be given a letter of information and informed consent.

This research will pose no threat to the school nor the participant. No risk or discomfort is anticipated in this research.

With your permission, the research will take place at Westville Boys High School. A sample size of 26 male water polo players. Core stability will be assessed on land and throwing velocity and jump height will be assessed in the pool. The process is expected to last no longer than 30 minutes per participant,

The dissertation is the final part of me obtaining my MTech: Chiropractic degree. Permission from you is required for me to utilize the swimming pool to conduct this research.

Your assistance would be highly appreciated and is vital to this research.

Attached is a letter of consent. Please read and sign accordingly.

Kind Regards
Ms N. McKenzie (B.Tech Chiropractic)
Researcher

LETTER OF CONSENT

- I hereby confirm that I have been informed by the researcher, Nicole McKenzie, about the nature, conduct, benefits and risks of this research
- I have also received, read and understood the above written information regarding this research
- I have had sufficient opportunity to ask questions and (of my own free will) hereby grant permission to use Westville Boy's High school as a venue.
- I understand that a copy of the end results of this research will be made available to me at my request

______________________	___________	______________________
Full Name of Principal	**Date**	**Signature**

I, Nicole McKenzie hereby confirm that the Principal has been fully informed about the nature, conduct and risks of this research.

______________________	___________	______________________
Full Name of Researcher	**Date**	**Signature**

______________________	___________	______________________
Full Name of Supervisor	**Date**	**Signature**

Appendix E: Participant letter of information

LETTER OF NFORMATION:

Title of the Research Study: The effect of core stability on male water polo players' jump height and throwing velocity.

Principal Investigator/s/researcher: Nicole McKenzie (B.Tech: Chiropractic)

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

Brief Introduction and Purpose of the Study: Core stability has been studied thoroughly and is known to be an important factor in overhead throwing athletes, as the limbs are unable to function optimally without a strong and stable core. However, there is no literature on the role of core stability when ground reactive forces are removed. This research aims to identify the relationship between core stability, jump height and throwing velocity.

Outline of the Procedures: Research will take place at Westville Boys High School. 26 participants will be required to undergo two tests to assess core stability and then throw the water polo ball into the goals as fast as possible. A video camera will be used to assess jump height and the speed of each shot will be measured using a speed radar gun. The process is expected to last no longer than 30 minutes per participant,

Risks or Discomforts to the Participant: No adverse effects are anticipated from this research

Benefits: This study will help increase all health care professional's knowledge in the treatment and rehabilitation program, helping athletes return to their optimal functioning level.

Commitment to the Study: Participants may withdraw from the study at any point for any reason without consequences.

Remuneration: There will be no remuneration offered.
Costs of the Study: There will be no cost involved in this study.

Confidentiality: Your information will be kept confidential and will be store at Durban University of Technology's Chiropractic department in a safe for five years. Thereafter it will be destroyed by a shredding machine.

Research-related Injury: You will not be injured during this research study.

Persons to Contact in the Event of Any Problems or Queries: Please contact the researcher, Nicole McKenzie (tel no: 0810437314), my supervisor, Dr Grant Matkovich (tel no: 0312018204) or the Institutional Research Ethics Administrator on 031 373 2375. Complaints can be reported to the Director: Research and Postgraduate Support, Prof Napier on 031 373 2326 or carinn@dut.ac.

Appendix F: Consent form for participant – above eighteen years

CONSENT:
Participant above the age of eighteen years

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Nicole McKenzie, about the nature, conduct, benefits and risks of this study
- 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 computerized 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**	**Signature**

I, Nicole McKenzie, 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	**Date**	**Signature**

Appendix G: Consent form for participant – below eighteen years

CONSENT:
Participant below the age of eighteen years

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Nicole McKenzie, about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: IREC 050/18.
- 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 computerized 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**	**Signature**
______________________	______________	________________
Full Name of parent/ legal guardian (if under the age of 18)	**Date**	**Signature**

I, Nicole McKenzie, 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	**Date**	**Signature**

Appendix H: Data collection sheet

Data collection sheet

Participant Name:		**Date:**	
Weight:	**kg**	**Age:**	
Height:	**m**		

1. PRONE test:

Can the core contraction be initiated? YES / NO

Ten second contraction	Compensatory movements	Change in pressure (> 2mmHg)	Time of sustained core contraction (> 4 sec)
Contraction 1	YES / NO		
Contraction 2	YES / NO		
Contraction 3	YES / NO		

2. SUPINE test:

Grade	Ability to maintain core contraction		Difference from set value at point in which the subject is unable to maintain core contraction	
	Right	**Left**	**Right**	**Left**
1A) Single leg slide with contralateral leg supported. Test leg slides the heel down the surface of the examination table.	YES / NO	YES / NO		
1B) Unsupported single leg slide with contralateral leg supported. Test leg is held approximately 5cm above the examination table, then slides above the surface of the examination table.	YES / NO	YES / NO		
2A) Single leg slide with contralateral leg unsupported. Contralateral leg is held approximately 5cm above the examination table, while the test leg slides the heel down the surface of the examination table.	YES / NO	YES / NO		
2B) Unsupported single leg slide with contralateral leg unsupported. Both legs held approximately 5cm above the examination table, test leg slides above the surface of the examination table.	YES / NO	YES / NO		

3. Jump height:

Throw	1	2	3
cm			
Mean max HH:	cm		

Throw	1	2	3
cm			
Mean HH ball release:	cm		

4. Throwing velocity:

Throw	1	2	3
Km/h			
Mean velocity:	Km/h		

Appendix I: IREC approval

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

P O Box 1334, Durban, South Africa, 4001

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

www.dut.ac.za

6 August 2018

Miss N A McKenzie
1 Glen Eden
12 Greenmeadow Lane
Hillcrest
3610

Dear Miss McKenzie

The effect of core stability on male water polo players' jump height and throwing velocity

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

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,

[redacted]

Professor J K Adam
Chairperson: IREC

DUT DURBAN UNIVERSITY OF TECHNOLOGY
2018 -08- 06
INSTITUTIONAL RESEARCH ETHICS COMMITTEE
P O BOX 1334 DURBAN 4000 SOUTH AFRICA