The immediate effect of lumbar spine manipulation, thoracic spine manipulation and placebo manipulation on range of motion and bowling speed in asymptomatic male and female indoor cricket bowlers

By

Prasanthi Nayager

Dissertation submitted in partial compliance with the requirements for the Master's Degree in Technology: Chiropractic

Durban University of Technology

I, Prasanthi Nayager, do declare that this dissertation is a representation of my own work in both concept and execution.

…………………………………..   Date: **………………………**

Prasanthi Nayager

Approved for Final Examination

…………………………………..   Date: **………………………**

Supervisor

Dr Praveena Maharaj

…………………………………..   Date: **………………………**

Co- Supervisor

Dr Kanwal Sood

DEDICATION

This dissertation is dedicated to my best friend, walking ATM, MasterChef, and Queen, my Ma. Thank you for all your love, support and guidance. Your support through my academic years have been tremendous. I love you always.

You have now become my Guardian Angel. I now miss and love you even more. Thank you for always being my pillar of strength, I hope you continue to walk with me throughout all the facets of my life.

I offer this dissertation at Thy Lotus Feet of my Saviour and Lord Bhagawan Sri Sathya Sai Baba. Thank you for your guidance and divine blessings upon my family and me, especially during my years of study.

To my family, thank you for supporting me during my years of study, emotionally and financially. Without the guidance and support of each one of you I would not have successfully completed my degree.

ACKNOWLEDGEMENTS

Blessed are those who have an amazing family like mine.

Thank you to my amazing parents for all the unconditional love and support through my years of study. To my dad for always rallying around me and being my personal chauffeur whenever needed and my Super Mom for financially supporting me and ensuring that I always had everything of the best. I do not often say this, but I love you all. Without your support, I would not have completed my studies.

To my pillars of strength, Ma and Geya ma, thanks for all the financial support and love showered on me. I love you my two Queens.

My brothers, Veroshin, Saiheshan and Kreolin, thanks for always spoiling me with chocolates, movies and lunches, and the unconditional love that you endlessly showed me.

My partner-in-crime and hookah mate, Nishalin, thank you for always being my confidante, best friend, distractor, and amazing baby brother.

My sisters, Quraisha, and Prenasha, I thank you both for all the love and support and for always being my experimental patients whenever I had to study for practical tests and exams.

To my aunts, and uncles, A girl is special if she has so many moms and dads and I know I am the luckiest. I thank each one of you for the unwavering support and your love. You have been my spinal column (backbone) throughout my life. I love you immensely.

To my incredible supervisor, Dr Praveena Maharaj, you are my inspiration, mentor, and role model. Thank you for always keeping me in line during my studies and for your steadfast support. You have guided me throughout my academic career, and I know it was not always easy. Thank you for always having the doors of your practice open to me and always being a phone call away. You are the best by far.

To Dr Sood my amazing co-supervisor. Thank you for all your assistance and guidance and a special thanks for always correcting my grammar and English whenever needed.

The amazing chiropractic lecturers: Thanks for all the guidance and support. Dr L. O' Connor, Dr Docrat, Dr Korporaal, Dr Varatharajullu and Dr Prince, thanks for all the assistance during my academic career.

To Dr Padayachy, thank you for the off-site supervision, being an amazing clinician, as well as a friend, laughing buddy and confidant.

To Dr Abdul-Rasheed, thanks for being an amazing lecturer, clinician, friend, laughing buddy and confidant. Lectures and clinic with you were eventful and fun.

To my awesome cricket girls: Thanks for all the fun, crazy moments and laughing at my not so funny jokes on the field and off the field. You were my distraction when needed. Love you always.

To Mr Deepak Singh, my statistician, thank you for your work in acquiring my stats and data.

ABSTRACT

Background:

Cricket bowling is a manoeuvre that consists of a sequence of body motions utilising the entire kinematic chain. Cricket like many sports is played both indoor and outdoor. To eliminate the factors of weather (dew and wind) and nature (grass top pitchers) the following study was conducted on indoor cricket bowlers. The phrase 'proximal stability for distal mobility' is best suited, as the lower extremities, pelvis and trunk play a vital role and assist the upper extremities in the bowling action. Therefore, bowling should be known as a combined movement of the entire body, culminating with rapid motions of the upper extremity. Restricted motion within a joint segment could lead to adverse changes in the surrounding muscles, tendons, and ligaments of the trunk. Restricted motion of the trunk and pelvis may result in abnormal loads being applied on the peripheral joints, thus resulting in injuries or a decline in an athlete's performance. Spinal manipulation therapy is a technique that is used to improve flexibility and mobility in a joint. This study focused on the effects of SMT on the joint range of motion (trunk) and bowling speed.

Objectives:

The main objective of this study was to assess the immediate effects of lumbar spine, thoracic spine, and placebo manipulation on the range of motion of the thoracic and lumbar spine, as well as the bowling speed of the participants.

Methods:

A sample of asymptomatic male and female cricket bowlers (60 in total), playing for schools, local clubs and at provincial level were divided into three groups of 10 each. Group 1a and Group 1b received thoracic spine manipulation, Group 2a and Group 2b received lumbar spine manipulation and Group 3a and Group 3b received placebo spinal manipulation. The range of motion of the thoracic and lumbar spine was measured pre and post manipulation using a digital inclinometer. Bowling speed was measured pre and post warm-up and manipulation using a speed radar. The participants' perception of changes in bowling speed post manipulation were also recorded. SPSS version 25 was used to statistically analyse the data.

Results:

There were statistically significant increases in thoracic range of motion post thoracic manipulation in male and female participants. Thoracic spine manipulation enhanced bowling speed significantly in male and female participants. Lumbar spine manipulation increased lumbar range of motion and thoracic range of motion, especially in the female athletes. However, it did not impact bowling speed. Post placebo manipulation showed that there were no significant differences in range of motion and bowling speed. However, both thoracic and lumbar manipulation showed significant changes in range of motion, compared to placebo manipulation.

Conclusion:

This study supported the findings of several authors, that spinal manipulation significantly influences athletes' performance. In this study, post thoracic spine manipulation bowling speed increased significantly in both male and female athletes. It was also evident that female participants' range of motion increased overall except for extension of the lumbar spine more post manipulation, while male participants had a higher bowling speed average.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF GRAPHS

LIST OF FIGURES

DEFINITIONS

Asymptomatic: Being asymptomatic refers to individuals who have no symptoms or illness (Tattersall 2001).

Core Stability: Traditionally, this term has referred to the active component of the stabilizing system, including deep/local muscles that provide segmental stability (transversus abdominis, lumbar multifidus) and the superficial or global muscles (rectus abdominis, erector spinae) that enable trunk movement or torque generation and also assist in stability in more physically demanding tasks Kibler *et al.* 2006).

Contraindications: A condition which makes a treatment or procedure potentially inadvisable. A contraindication may be absolute or relative (Venes *et al.* 2001).

Extension: Movement that occurs in the sagittal plane, that increases the angle between two body parts (Moore, Dalley and Angus 2015).

Flexion: Movement that occurs in the sagittal plane, that decreases the angle between two body parts (Moore, Dalley and Angus 2015).

Inertia: A property of matter, by which it remains at rest or in uniform motion in the same straight line, unless acted upon by some external force (Dourmaskin 2013).

Joint Complex: A joint composed of three or more skeletal elements, or in which two anatomically separate joints function as a unit (Bergmann and Peterson 2010).

Joint Dysfunction: The disturbance of function without structural change, affecting range of motion. It can present as a change in motion, be it an increase or decrease (Bergmann and Peterson 2010).

Kinetic Chain: The kinetic chain (sometimes called the kinematic chain) is an engineering concept used to describe human movement. It is used in a wide variety of clinical conditions, including musculoskeletal and sports medicine (Karandikar and Vargas 2011).

Lateral flexion: These are movements in the frontal plane about the sagittal axis and involve moving the body part away or towards an imaginary centre line (Moore, Dalley and Angus 2015).

Rotation: Rotation movements are in the transverse plane and include any twisting motion (Moore, Dalley and Angus 2015).

Spinal manipulation: Manipulation is a passive technique where the therapist applies a specifically directed manual impulse, or thrust, to a joint, at or near the end of the passive range of motion (Rubenstein *et al.* 2011)

Trunk: The part of the body excluding the head and limbs; therefore, the bony anatomy of the trunk includes the thoracic and lumbar spine (Moore, Dalley and Angus 2015).

LIST OF ABBREVIATIONS

CNS:	Central Nervous System
Deg.:	Degrees
Ext:	Extension
FF:	Forward Flexion
IVD:	Intervertebral Disc
IVF:	Intervertebral Foramina
Kg:	Kilogramme
Km/h:	Kilometres per hour
KZN:	KwaZulu-Natal
L1-5:	Lumbar vertebrae with corresponding number
LLF:	Left Lateral Flexion
LPA:	Left Posterior-anterior
L/S:	Lumbar spine
N:	Number
RCT:	Randomized Controlled Trial
ROM:	Range of Motion
RLF:	Right Lateral Flexion
RPA:	Right Posterior-anterior
Sig:	Significant
SMT:	Spinal Manipulation
T1-12:	Thoracic vertebrae with corresponding number
T/S:	Thoracic spine
UNIANOVA:	Unilateral Analysis of Variance
Z:	Significant

CHAPTER ONE

1.1 INTRODUCTION

In cricket, bowling is a manoeuvre that involves the bowler propelling the ball for 17.6 metres. Traditionally, it is understood that the shoulder complex generates the force required to propel the ball. However, several authors (Meister 2000; Matsuo T 2001; Burkhart, Morgan and Kibler 2003; Seroyer *et al.* 2010) postulated that the force generated by the shoulder complex is not adequate for maximal ball propulsion. The shoulder complex serves as a funnel and regulates the throwing force that is generated by other areas of the body. According to Seroyer *et al.* (2010), the trunk and lower extremity generate and transmit energy to the upper extremity. This coordinated motion of the lower extremity provides stability for the trunk to flex, extend, rotate, and laterally flex. Thus, trunk mobility contributes to the throwing or bowling force and thus the ball release speed.

Blalock *et al*. (2015) stated that a restricted motion within a joint complex result in adverse changes in the surrounding ligaments, tendons, muscular tissue, and vascular elements. The implications of the above changes are a loss of tensile strength, adhesions, loss of flexibility and range of motion (ROM), and muscle atrophy leading to a loss of functional ability (Gatterman 2004 and Blalock *et al.* 2015). Thus, to improve trunk mobility, this study focused on spinal manipulation, as this has been reported to safely and effectively improve spinal mobility, enhance trunk flexibility and assess its effect on bowling speed (Bergman and Peterson 2010 and Yang *et al.* 2015).

1.2 AIMS AND OBJECTIVES

1.2.1 Aims

The primary aim of this study was:

- To determine via a controlled, prospective, clinical trial the immediate effectiveness of thoracic, lumbar, and sham spinal manipulation on range of motion and bowling speed in asymptomatic indoor cricket bowlers registered in the KwaZulu-Natal Cricket Union (KZNCU).

1.2.2 Objectives

Several specific objectives were identified, and these comprised of:

Objective One:

To determine the immediate effect (pre and post intervention) of lumbar spine manipulation on the lumbar range of motion and the bowling speed in indoor cricket bowlers, in terms of the subjective (related to bowling speed only) and objective measurements.

Objective Two:

To determine the immediate effect (pre-and post-intervention) of thoracic spine manipulation on the thoracic range of motion and the bowling speed in indoor cricket bowlers, in terms of the subjective and objective measurements.

Objective Three:

To determine the immediate effect (pre-and post-intervention) of placebo spinal manipulation technique on the lumbar spine and thoracic spine range of motion and the bowling speed in indoor cricket bowlers, in terms of the subjective and objective measurements.

Objective Four:

To compare the subjective and objective change in bowling speed post manipulation in each participant.

Objective Five:

To determine the relationship between the immediate change in bowling speed pre and post intervention and the participants perception of the change in bowling speed.

1.3 HYPOTHESIS OF THE STUDY

For the objectives of this study, the Null Hypotheses (Ho) were set as follows:

- There would be no statistically significant increases in bowling speed post intervention for any of the three groups.
- There would be no statistically significant increases in range of motion for any of the three groups.
- There would be no statistically significant relationship between immediate change in bowling speed post intervention and an immediate change in range of motion of the lumbar spine and/or thoracic spine.
- There would be no statistically significant relationship between measured change in bowling speeds immediately post intervention and the participants' perception of change in bowling speed.

1.4 SCOPE OF THE STUDY

The results of 60 asymptomatic male and female indoor cricket bowlers, for clinical musculoskeletal symptoms, and who met all the inclusion criteria of the study are presented in this dissertation. The participants were divided into three equal groups of 10 each. Group 1a and Group 1b received thoracic spine manipulation, Group 2a and Group 2b received lumbar spine manipulation, and Group 3a and Group 3b received a sham spinal manipulation.

The objective measurements included range of motion (flexion, extension, lateral flexion, and rotation) of the thoracic and lumbar spine and the bowling speed of each participant. The range of motion measurements of the thoracic and lumbar spine were performed pre and post warm-up routine and post intervention with the digital inclinometer. Bowling speed measurements were recorded pre and post intervention. The participants' perception of their change in bowling speed post intervention was also recorded via a questionnaire.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

Cricket being a revolutionised sport has been in existence for hundreds of years. This sport is played between two teams, consisting of batters, fielders, and bowlers. A bowler is an individual who has acquired the skill to propel a cricket ball, and this action is called bowling. Bowling is differentiated from throwing as the throwing arm elbow is extended and not flexed (David 2008). Cricket can be played both indoor and outdoor, with very little differences in the rules monitoring the game. Indoor cricket eliminates external factors (weather, dew, pitch, and grass).

The overhand bowling motion consists of a sequence of body movements that begins when the bowler lifts the lead foot, progresses to a linked motion in the hips and trunk, and culminates with a ballistic motion of the upper extremity to propel the ball (Seroyer *et al.* 2010). The lower extremity and trunk generate and transfer energy to the upper extremity. The coordinated lower extremity musculature (hamstrings, quadriceps, and hip internal and external rotators) provide a stable base for the trunk to flex and rotate. The forward linear trunk motion and external rotation of the shoulder allow a greater distance for the accelerating force to be applied to the ball, producing a higher velocity (Seroyer *et al.* 2010). The bowling motion occurs almost exclusively above 90 degrees of abduction. The deltoid muscle raises the humerus, while the rotator cuff corrects the position of the humeral head on the glenoid. The pectoralis major and latissimus dorsi power the shoulder forward (Seroyer *et al.* 2010).

A bowler's velocity, durability and consistency can be linked to the kinematic and kinetic factors, as well as segmental body movements (Seroyer *et al.* 2010 and Schaefer *et al.* 2017). The pitching motion consists of many phases. When these phases are intricately coupled, it results in the transfer of energy from the body into the arm and eventually the hand and ball (Seroyer *et al*. 2010. The legs and trunk serve as the most important force generators of the kinetic chain (Burkhart, Morgan and Kibler 2003).

According to Stodden *et al.* (2005), the complex interaction of the core musculature and lower extremity in the kinetic chain decreases the kinetic contributions of the glenohumeral joint. Therefore, the bowling motion should not be perceived as an upper extremity action, but rather a combined movement of the whole body that culminates with rapid movement of the upper extremity. Stodden *et al.* (2005) and Seroyer *et al*. 2010 reported that forward trunk flexion allowed the ball to move through a greater distance, thus producing a higher ball velocity. In summary, body mass, and the 9 temporal and kinematic parameters related to pitching mechanics combine to account for a variance in ball velocity in the bowling athletes.

Fast bowling in cricket requires the bowler to rapidly flex, laterally flex, and rotate the thoracic and lumbar spine to generate a high velocity of ball release. The thoracic spine is susceptible to injury due to movement in all ranges of motion (Crewe *et al.* 2012). Lumbar spine injuries are the most common injuries (40-45%) sustained by cricket bowlers (Elliott and Khangure 2002). Fast bowlers Participant their spines to repetitive sagittal plane and rotatory movements, over many years, placing them at a higher risk of back injuries (Stretch and Venter 2005; Trella 2012). Disc degeneration occurs at a higher rate in fast bowlers, compared to the non-athletes, due to repetitive stresses, especially at the point of maximal load transmission during the delivery stride phase of bowling (Schaefer *et al*. 2017).

As stated above cricket bowlers are susceptible to several injuries due to the bowling motion and impact it has on the trunk. If a bowler has any of the above injuries, then he/she would be unable to propel the ball at moderate to high velocity, thus affecting their performance levels, as biomechanically the trunk is unstable. According to Wallis, Elliot and Koh (2002) injuries in the mid to low back have shown to be a concern for bowlers of all ages and abilities. The above authors stated that the restriction applied by the harness produced a significant decrease in the separation angle and forced the bowler to adopt a reduced rotatory movement in the spine (Wallis, Elliot and Koh 2002). The improper transfer of energy may cause abnormal stressors on the joints and this could lead to a decrease in function, injury and or reduced performance (Robson 2018).

2.2 OVERVIEW OF CRICKET

2.2.1 Description

According to David (2008), indoor cricket is arguably one of the oldest sports in the world. Studies indicate the game was first played in the early 1300s. Since the 17th century cricket has evolved enough to be recognizable as a distinct game. It has been concluded that indoor cricket gave rise to outdoor cricket. It is believed that cricket survived as a children's game for many generations before adults increasingly took it up around the 17th century. The first ever cricket match was played in England, between Kent and Surrey (David 2008).

Indoor cricket is predominantly played between two teams consisting of 8-10 players each, one of whom is the wicketkeeper. Professional indoor cricket is played on a synthetic pitch in an arena that measures 30 meters x 12 meters, and which is enclosed by a netting 4.5 meters high (Hughes 2001).

Professional outdoor cricket is played in an oval arena on a rectangular pitch, which is 22.56 meters (32 feet) in length (**Figure 2.1**). The essential equipment required consists of a bat, ball, and a pair of wooden stumps (**Figure 2.2**) (Hughes 2001). The wooden stumps are placed at the head and foot of the pitch.

The main objective of the game is for the batting side to score as many runs as possible, and for the fielding side to take 10 wickets (to remove all the batting side players and limit the runs). Two players from the batting side are initially sent out onto the crease to bat, while the fielding side has 8-10 players in the arena: the bowler (bowls the ball over arm towards the batter, with the aim to get the batter out), fielders (their task is to limit the batters runs and to get the batter out by catching and or throwing the ball in different circumstances) (**Figure 2.3**) and a wicket-keeper (stands behind the wickets (stumps) and stops the ball if the batter misses it) (David 2008).

A bowler has the chance to bowl six consecutive balls to the batter, this is termed an over. If the ball is bowled wide of the crease, it is called a wide ball and if it is bowled above waist height or if the bowler oversteps the crease line, this is termed a no-ball, and the batting side is awarded one run. A new over commences once 6 legitimate balls are bowled (Hughes 2001; Thomas 2007; David 2008).

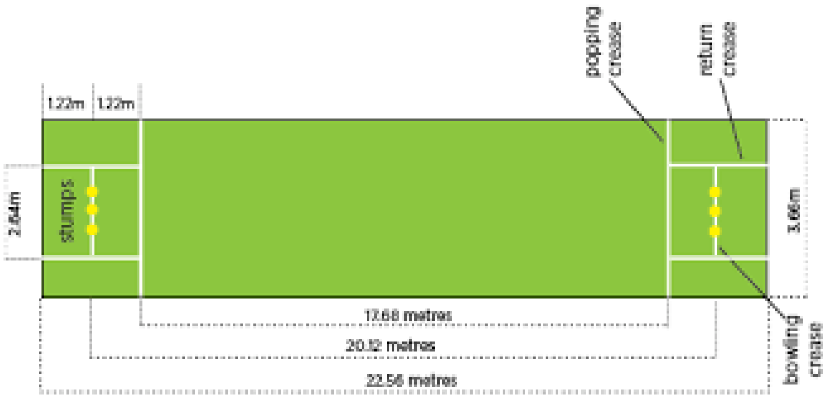


Figure 2.1: Cricket pitch with dimensions (James, Carré and Haake 2005)

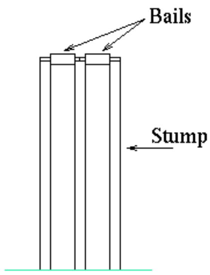


Figure 2.2: Stumps with bails (James, Carré and Haake 2005)

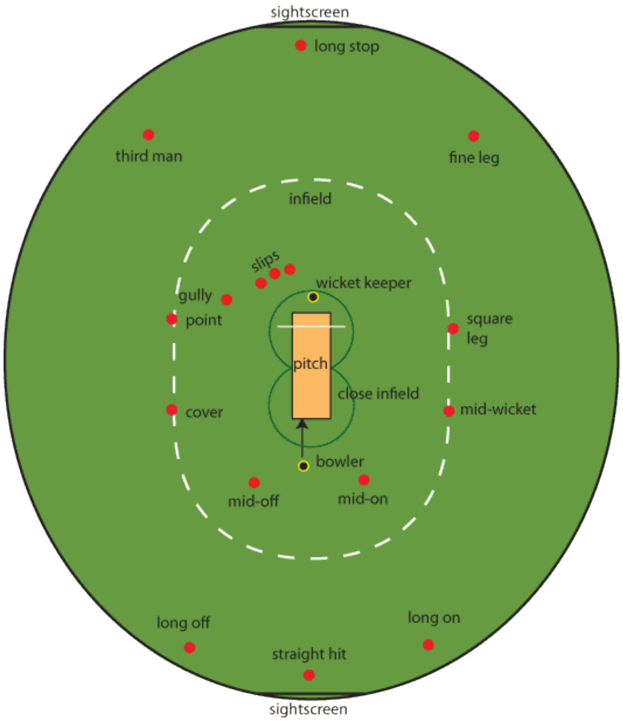


Figure 2.3: Cricket field and fielding positions (James, Carré and Haake 2005)

2.2.2 Types of Cricket

Cricket can be played both indoor and outdoor (Thomas 2007):

> *"The characteristic features of indoor cricket include a synthetic pitch, a soft yellow ball, a set of rubber stumps and a shorter bowling run-up used by the bowler. The team consists of eight players, an innings consists of eight overs, the arena measures 30 meters x 12 meters and is enclosed by a netting 4.5 meters high. The bowlers are each allowed a maximum of two times eight ball overs and the batters must each bat together in partnership of four overs."* (Thomas 2007)

Outdoor cricket features include a grass pitch, a set of wooden stumps (wickets), a hard, red ball and a longer run-up is used by the bowler. The teams each consists of 11 players, an innings will consist of a minimum of 20 overs, and the arena measures between 137 – 150 metres (Thomas 2007). Depending on the type of match, bowlers can bowl a minimum of four overs and the batters can bat the entire innings, as long as they do not lose their wicket.

There are 3 different formats of professional cricket (Hughes 2001; David 2008):

- **Twenty-Twenty (T20) Cricket**

  This is a different form of limited overs cricket and is the third form of cricket. Each team has one innings, in which the maximum number of overs are 20.

- **One Day International (ODI)**

  Limited overs cricket is the second form of cricket, in which each team may bowl between 40 to 60 overs. A bowler is restricted to bowl a maximum of 10 overs.

- **Test Cricket**

  This is the main form of cricket and is played over a period of five days, each day consisting of a maximum of 90 overs. The bowlers are not restricted in the amount of overs that need to be bowled individually.

The use of an indoor facility rules out the effects of dew, weather (wind) and the pitch, as these tend to play a vital role in the type of ball being delivered (in-swinger, out-swinger) and the bowling speed.

2.3 BOWLING

2.3.1 Description

This is the action of propelling the ball towards the wicket which is defended by the batter. A player who has acquired the skill to bowl is called a bowler. Bowling differs from throwing of the ball, due to its biomechanical definition, which restricts the angle of elbow extension. A bowler can bowl six legal deliveries. If a ball is bowled incorrectly or too wide from the batter, it is termed no-ball or wide and it will need to be re-bowled (Hurrion and Harmer 2002).

The simultaneous twin objectives of bowling are to take wickets and reduce run scoring. These are achieved through disciplined bowling of line and length, pace, and swing. The bowler bowls the ball in a way as to restrict the batter from scoring, by preventing the ball from contacting the middle of the bat (the ball can pass the outer or inner aspect of the bat) (Hurrion and Harmer 2002).

2.3.2 Types of Bowling

There are several types of bowlers: fast, seam and spin bowlers (Hurrion and Harmer 2002).

2.3.2.1 Fast Bowling

This is one of the main approaches to bowling in cricket. The aim of fast bowling is to propel the ball in such a manner as to cause the batter to play a false stroke. This is attained by making the cricket ball deviate from a predictable linear motion at a speed that reduces the reaction time of the batter. There are a few different types of fast bowling: swing, seam, and strike bowling. Swing bowlers make the ball move laterally through the air. There are two types of swing bowling, in-swinger (the ball moves into the batter) and an out-swinger (the ball moves away from the batter). This type of bowling is dependent on the position of the seam (stitching on the ball). Seam bowling is when the seam of the ball is used to make the ball bounce in an unpredictable manner when the ball strikes the pitch. Strike bowlers are used mainly to get the batter out. This is achieved through speed, accuracy and aggression (Hughes 2001; Hurrion and Harmer 2002).

2.3.2.2 Spin Bowling

This is the second form of bowling. Spin bowlers deliver the ball at a slower pace and add spin to the ball, causing it to propel off the pitch inwards or outwards. The aim of spin bowling is to deliver the ball with rapid rotation so that when it hits the pitch it will deviate from its original line and length (Liebenberg 2010).

2.3.3 The Bowling Action

The bowling action is distinguished from throwing, in that the elbow joint must not straighten out. In bowling, the flexion of the elbow is prohibited, and full extension of the elbow is considered throwing, thus a bowler is allowed up to 15 degrees of extension or hyperextension. Bowlers must hold their elbows fully extended and rotate the arm vertically around the shoulder axis to transfer velocity to the ball, thereby releasing it close to the top of the arc (Hurrion and Harmer 2002; Liebenberg 2010).

Bowling actions are classically divided into side-on, front-on and mixed movements:

- **Front-on action** – the bowler has a high run-up speed and the rear foot points to the direction the ball is being delivered. The rear foot strikes the ground perpendicularly to the bowling crease and points down the pitch, making the hips parallel to the crease. The bowler aims at the stumps by looking inside the line of his forward-facing arm. The non-bowling arm is placed to the side of the head, thus aligning the shoulders and chest parallel with the bowling crease and hips (Summer 2015).
- **Side-on action** – this is a more commonly used action. The bowler looks behind the front arm during delivery to have sight of the target. The back-foot lands parallel to the bowling crease, causing the hips to be side-on and the bowler aims at the stumps by looking over his forward-facing shoulder. This means that the bowler's shoulders are aligned square to the batter when delivering the ball, thus the shoulders are 180º with the rear foot position being parallel to the bowling crease. The non-bowling arm is placed in front of the head; therefore, the shoulders are aligned with the hips (Summer 2015).
- **Mixed action** – when the bowler incorporates both front-on and side on actions to deliver a ball. However, this is prohibited in young individuals as it could lead to excessive stress to the low back.

The above bowling actions assist the bowler in propelling the ball. During the bowling motion, a sequence of different body motions occur, whereby the front foot lands, progressing to a linked motion between the hip and trunk, and thus culminating with the upper extremity releasing the ball. The pelvis and spine transmit forces down the kinetic chain during the bowling sequence.

As stated by Worthington *et al.* 2013 fast bowlers had a faster run-up, maintained a straight (extended) front knee throughout front foot contact, and displayed a greater upper trunk flexion between front foot and ball release. Thus, to generate a high ball release speed the entire body linear motion as generated by the run-up is then converted to whole body angular motion about the mass centre. These cause the front foot contact to halt the lower half of the body and accelerate the upper half of the body towards the target. The excessive amount of upper trunk flexion represents a more effective conversion of linear motion to angular motion, thus resulting in a delay in the bowling arm due to the upper trunk flexion, as more trunk flexion requires a delayed bowling arm.

2.3.3.1 Stages of the Bowling Action

In cricket, the bowling action is a set of actions that result in the bowler propelling the ball in the batter's direction. The bowling action can be divided into the following steps: approach (run-up), bound (pre-delivery), delivery stride (back and front foot), point of release and follow through. The bowling action can be clearly understood by simply understanding Newtons first and second laws.

- **Approach (run-up)** –The bowler's approach begins with shorter strides, and he/she then jogs over the marker, steadily increasing speed on the approach to the wicket with arms tucked in. The increase in speed is greater than the inertia, and thus the ball moves from rest (first law). The ball gains acceleration as the bowler's speed increases, and thus the ball will have a greater speed depending on the bowler's speed (second law). The approach ends as the bowler leaps into the air at the start of the bound in preparation for the delivery stride (**Figure 2.4**). When the bowler's foot strikes the ground, it causes a reaction where the foot moves superiorly in a vertical and horizontal force to then propel inferiorly, striking the ground (Summer 2015). Run-up lengths vary depending on the bowler, it ranges from nine meters to 22 meters (30 – 70 feet) (Liebenberg 2010).

- **Bound (pre-delivery)** – this is a jump that allows the bowler to transition from the run-up to the back-foot contact position (**Figure 2.4**). The trunk rotates and extends away from the batter. The front-on bowlers have a low, short bound, and therefore transition is not required. However, side-on bowlers must rotate their bodies through 90 degrees, and thus they have a longer, higher bound (Summer 2015).
- **Delivery stride** – this follows the pre-delivery stage and is the stride through which the delivery swing is made. It commences when the bowler's back foot lands for that step and ends when the front foot lands in the same stride (**Figure 2.4**).
    - **Back foot contact –** this is the commencement of the delivery stride and is when the back foot strikes the ground just before the ball is delivered (**Figure 2.4**). Most of the bowler's weight is transferred onto the back foot, which assists in pulling momentum from the bowler's trunk to laterally flex away from the target. The purpose is to maintain the acceleration that has been accumulated by using the ground reaction forces. The back foot could lie parallel to the crease or point down the pitch. The head is still, and the ball is held close to the chin. This tucked in position permits the ball to be carried through in an arc that is aligned with the wickets. The bowler's trunk is laterally flexed, this assists in increasing the acceleration of the ball (Summer 2015).
    - **Front foot contact –** this is when the bowler's front foot strikes the ground just before the ball is delivered, the ball is delivered thereafter (**Figure 2.4**). Newton's third law explains this phase. When the front foot strikes the ground, it accelerates the trunk position forward and an equal or opposite force occurs when the ball is delivered (Liebenberg 2010). This is all dependant on the bowler's trunk flexion. A side-on bowler has a greater trunk flexion because momentum is generated during the delivery

phase, while a front-on bowler generates speed from the run-up, thus less trunk flexion is required. Therefore, trunk flexion and braking force is essential in ball release speed (Summer 2015).

- **Point of release –** this is the position of the ball in relation to the body at the moment when the ball is released (**Figure 2.4**). The arm should be stiff and the wrist loose to ensure a smooth release of the ball; the shoulder should be facing the stumps, the arm beside the bowler falls away. An anti-clockwise force is produced when the non-bolwing arm is pulled towards the trunk. This results in the bowler having a greater centre of gravity, and thus greater momentum is generated (Summer 2015).
- **Follow through –** this is the final stage. The momentum generated from the above movements allows the bowler to move along the pitch, gradually decreasing in speed (**Figure 2.4**).

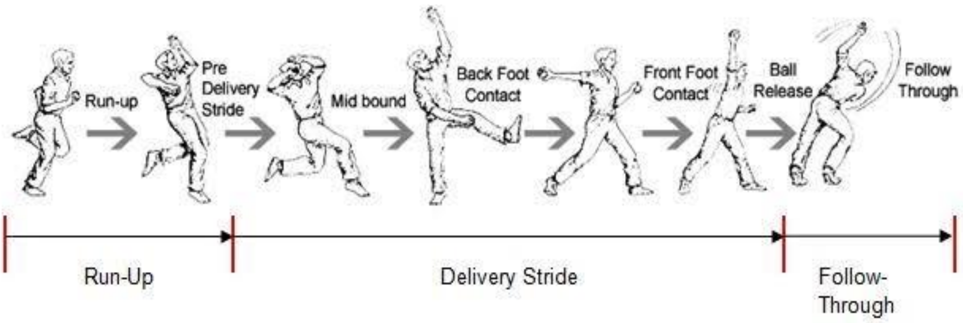


Figure 2.4: The bowling action/technique (James, Carré and Haake 2005)

2.3.4 Biomechanics of the Bowling Action

Because there is very little relevant literature on cricket bowlers, this study has had to compare the motion of bowlers to the American game of baseball, and the movements of pitchers. Cricket bowlers are not restricted to a small strike zone as the target and are able to use several approaches. However, this is not applicable to baseball pitchers. Cricket bowlers deceive the batters by varying their line and length and using an unpredictable movement caused by the bounce of the ball on the pitch, while baseball pitchers utilize the ball speed, as well as movement changes caused by air friction. Despite the few differences between baseball pitching and cricket bowling, the biomechanical chain presents similarly in the arm and trunk of both actions (Liebenberg 2010; Seroyer *et al.* 2010). The pitching motion comprises of 6 phases:

- **Windup** – in this phase the body generates the force and power required to attain a great velocity. It commences with the movement of the contralateral leg and culminates with the elevation of the lead leg to the highest point and the separation of the throwing arm. The centre of gravity is maintained over the back leg to enhance maximum momentum once forward motion occurs (Meister 2000).
- **Early cocking** – this commences when the lead leg reaches maximum height and the ball is removed from the glove and culminates when the lead foot strikes the ground. This phase is essential for an increase in distance of the linear and angular trunk motions, and thus increasing the energy produced for the upper extremity. Pelvic rotation, forward tilt and upper trunk rotation occur once the stance knee and hip extend. During the cocking phase hyperextension of the lumbar spine is restricted due to the eccentric contraction of the abdominal oblique muscles. The dominant leg's gluteus maximus provides stability for the trunk and pelvis. The SITS muscles externally rotate the shoulder, which places the humeral head in the glenoid fossa and the scapular retractors to provide stability to the humerus during rotation. The front foot lands in line with the stance foot, directed towards the home plate (Seroyer *et al.* 2010).
- **Late cocking** – this commences when the lead foot strikes the ground and the throwing shoulder reaches maximal external rotation. The scapula retracts, elbow flexes, humerus abducts and externally rotates, the pelvis reaches maximum rotation and the upper trunk rotates forward and laterally flexes. As the upper trunk rotates, the pectoralis major and anterior deltoid move the throwing

arm into a horizontal adduction position for the launching of the ball (Stodden *et al.* 2005).

- **Acceleration** – this is the time during maximal shoulder external rotation and ball release. The trunk continues to rotate and flex, transmitting energy to the upper extremity. The scapula protracts to provide stability to the humerus when it horizontally adducts and internally rotates. The paraspinals, abdominal obliques, elbow extensors, elbow flexors and wrist flexors all aid in providing support for the pelvis and trunk and assist in adequate ball release (Werner *et al.* 2008).
- **Deceleration -** this occurs between ball release, maximal humeral internal rotation, and elbow extension. Internal rotation occurs during eccentric contraction of the scapular and humeral stabilizers. This phase culminates with completion of humeral rotation, shoulder abduction and an increase in horizontal arm adduction. The greatest amount of joint loading occurs during this phase. Once the ball is released, the upper extremity is outstretched, the elbow flexed and the arm is abducted (Meister 2000).
- **Follow through** – this phase brings an end to the throwing action. The arm is horizontally adducted, and knee extended, with minimal joint loading.

According to Ranson *et al.* 2008, Stuelcken, Ferdinands and Sinclair (2010), the thoracic spine, lumbar spine, and pelvis play a vital role in the bowling action. Ranson *et al*. 2008, stated that trunk extension, flexion, contralateral lateral flexion, and ipsilateral rotation all occurred during the delivery stride in the bowling action. The above trunk movements occurred during the front foot contact, back foot contact, and ball release. Ranson *et al.* 2008 stated that cricket fast bowlers tend to use a greater proportion of available lower trunk ROM during the delivery stride. During the delivery stride cricket fast bowlers used approximately 1.3x the mount of lateral flexion than compared to standing ROM (Ranson *et al.* 2008). According to Stuelcken, Ferdinands and Sinclair (2010), fast bowling has received considerable amount of attention due to the movement patterns of the thoracic and lumbar spines during the delivery stride in the bowling action. Several authors (Ranson *et al.* 2008, Stuelcken, Ferdinands, and Sinclair 2010) stated that trunk flexion, extension, contralateral lateral flexion coupled strongly with axial rotation was necessary to release the ball during the bowling action.

2.4 BOWLING SPEED

This is how fast or slow a bowler can propel the ball towards the batter and is the speed at which the ball leaves the hand and reaches the batter. This is a major contributor to the success of fast bowling. Bowlers can decrease the time the batter has to make decisions regarding the shot that will be played by increasing the speed that the ball is delivered. The ball release speed is entirely dependent on the bowler (Worthington, King and Ranson 2013).

2.4.1 Classification of Bowling Speed

There are several types of bowling speed: fast, fast medium, medium, and slow. **Table 2.1** depicts the different bowling speeds in male and females (Worthington, King and Ranson 2013).

Table 2.1: Different bowling speeds in male and females

Types km/h	Male	Female
Fast	>145	>131
Fast-medium	130-144	120-130
Medium-fast	120-129	109-119
Medium	100-119	85-108
Slow	<99	<84

These speeds may not apply to indoor cricket bowlers as there are slight differences in the run up and playing surface. The average speed in indoor cricket bowlers range from 85 to 125 km/h in males and 65 to 110 km/h in females (Thomas 2007 and Tapp 2019). Bowling speed is measured using a speed radar or gun. Baseball pitching speed and golf swing speed are similarly measured using a speed radar, as in cricket bowling. A speed gun is used to assess the pitching velocity in baseball and is placed behind the home plate. A swing speed radar is a sensor that measures the clubhead velocity in golfers. It assists the players in optimizing their swing mechanics. Chu *et al* (2009), stated that despite the difference in the delivery action, cricket fast bowling and baseball pitching speeds are similar, with the fastest balls being 95-100 mph or 150-160 km/h. According to Felton *et al.* 2018 cricket fast bowling and baseball pitching have similarities in bowling and pitching speeds. However, there are differences in bowling speeds when comparing male to female bowlers.

Chu *et al.* (2009) conducted a study between male and female baseball pitchers that suggested that females shared many similarities with males in pitching kinematics, with a few significant differences. Specifically, at the instant of stride foot contact, a female pitcher had a shorter and more open stride and less separation between pelvis orientation and upper torso orientation. From foot contact to ball release, a female pitcher produced lower peak angular velocity for throwing elbow extension and stride knee extension. Ball velocity was lower for the females. Foot contact to ball release took more time for a female pitcher. Maximal proximal forces at the shoulder and elbow joints were less for a female pitcher. Similarly, Felton et al. 2018 had found the same findings when he assessed the biomechanics in male and female cricket bowlers.

Felton *et al.* 2019 stated that men were stronger, had broader shoulders and longer arm lengths when compared to females; therefore, men were able to propel the ball at a faster rate. Females, being smaller physically, propelled the ball differently. This is primarily due to the difference in their musculature. Felton *et al.* 2019 stated that broader shoulders, a muscle mass of 40% and a total body fat of 15% on average allows men to propel the ball further and faster. On average, females have a muscle mass of 23% and 25% of body fat.

Zheng *et al.* (2008a) assessed club-head-velocity (CHV) speed between male and female golfers. Males generated 75mph speed compared to females 60mph. Due to the physical differences between males and females, there were different results obtained in the studies. The body mass index (BMI) or muscle mass may differ in males and females, but the spine, which lies between the skull and the pelvis, is similar. The primary functions of the human spine are to withstand body weight and control movement.

2.4.2 Factors that Affect Bowling Speed

The effects of increased pelvis and upper torso rotational velocities (Worthington, King, Ranson 2013); trunk forward flexion at ball release; increased shoulder and elbow proximal force; increased elbow flexion torque; decreased horizontal adduction at front foot contact, and changes in relative temporal parameters indicate that when a pitcher increased ball velocity, it occurred due to the effective transfer of momentum in the kinetic chain. The complex interaction of the three increased kinetic variables indicates that increased elbow flexion torque serves to limit the increases in shoulder and elbow proximal forces (Stodden et al. 2005). For the sake of this study trunk mobility will be described in more detail.

2.5 THE ROLE OF THE THORACIC AND LUMBAR SPINE IN THE BOWLING ACTION

Gilchrist, Frey and Nadler (2003) postulated that the lower limb joints function as a link system (kinetic chain) transitioning the forces produced during movements like jumping, running, and kicking into the pelvis and spine. The pelvis and spine transmit forces down the chain during the above movements. The overhead throwing action occurs due to the activation of the kinetic chain. According to Chu *et al.* (2016), the core and lower extremities provide stability and generate energy, which is transmitted to the throwing arm and hand, thus resulting in ball release. According to Seroyer *et al*. (2010), the lower extremity and trunk are the vital force generators in the kinematic chain, thus aiding the proximal limbs (shoulder, arm, and hand), during the throwing motion.

Oliver and Keeley (2010) postulated that the trunk contributes 50% of kinetic energy and force during the throwing or bowling action, and thus failure of this kinetic energy would predispose an athlete to injury and may result in a decline performance. During foot contact, an inverse relationship was noted between axial torso rotation and the plane of shoulder elevation, and this relationship showed that the axial torso relation was responsible for 60% of variance in the plane of shoulder elevation, and thus this relationship is significant due to the occurrence of overuse injuries. Oliver and Keeley (2010) indicated that although pelvic-torso motion was inversely related to shoulder plane elevation during pitching, the axial torso rotation is significantly related to the shoulder parameters, and thus explaining the importance of the trunk during the throwing motion. An increase in upper trunk flexion escalated bowling speed as bowlers generated speed using their upper trunk (Worthington, King and Ranson 2013). Worthington (2010) stated that trunk flexion positively influences ball release speed. Trunk flexion between 11 – 13 degrees produces greater ball release speeds.

During the bowling cycle, the sequence of proximal to distal segmental motion could be used to understand the magnitude and onset of rotational torques at the glenohumeral joint. Once pelvis rotation occurs, the trunk rotates, and the shoulder abducts. The trunk rotation causes external rotation of the glenohumeral joint, thus placing the joint outside the normal active range of motion (Sabick *et al.* 2004). This position is known as the "lag" because the throwing or bowling arm gradually lags during trunk rotation when it occurs early in the bowling motion. Aguinaldo, Buttermore and Chambers (2007) reported that shoulder internal rotation torque countered the lag movement, and thus peaking at maximum external rotation. Therefore, in the less skilled bowlers, the earlier trunk rotation occurs, will cause the shoulder to lag, thus leading to an increase in internal rotation torque. Based on the above findings, potentially harmful rotational torques might be reduced if trunk rotation was delayed, permitting the shoulder joint to "catch up" with segmental body movement.

Oliver and Keeley (2010) claimed that the pelvis and torso are essential not only in athletic performance, but also in injury prevention. Sharrock *et al.* (2011) reported that core stability is vital for optimal transfer of energy from the lower to upper extremities. Kibler, Press and Sciascia (2006) and Oliver *et al.* (2018) stated that the lumbosacral, pelvis, hip complex and core permits proximal stability for distal mobility.

Hirashima *et al.* (2008) discussed that there is a significant relationship between trunk and shoulder torques and elbow and wrist rotations. They found that the proximal joint movements increased due to joint torques at that specific joint, while the distal joint movements were enhanced by the velocity dependent torque, i.e. trunk and upper arm. These findings indicated that the elbow and wrist were entirely dependent on the trunk and shoulder for acceleration and release of the ball.

Stodden *et al.* (2005) conducted a study on the effect of trunk and pelvic motion kinematics on baseball pitchers. At the stride foot contact, a pitcher threw with his or her shoulder in a horizontally abducted position, the pelvis and upper torso had increased angular velocities and trunk flexion increased, thus resulting in a quicker ball release. As the pitcher rotated the upper trunk, the humerus had to counteract an increased horizontal abduction angle, and this led to an increase in time it took to reach maximum horizontal adduction. A decreased horizontal adduction at foot contact and increased trunk flexion at ball release suggested that the distance the ball travelled from stride foot contact to release increased as the ball speed increased (Stodden *et al.* 2005).

During the early cocking stage, the stance knee and leg extend thus activating pelvis rotation, trunk flexion and upper torso rotation. The pelvis reaches maximum rotation; whereas the abdominal oblique muscles contract to limit hyperextension of the lumbar spine during upper torso rotation and trunk flexion (Seroyer *et al.* 2010). The trunk transits from hyperextension to a forward flexed position, maintaining a lordotic curve. As the pitcher moves into the late cocking phase, the pelvis reaches maximum rotation, the trunk flexes and laterally flexes the lead knee extends to permit further trunk flexion. During trunk flexion, the pectoralis major and anterior deltoid place the throwing arm in the horizontally adducted position for ball release (Seroyer *et al.* 2010).

Seroyer *et al.* (2010) reported that during the acceleration phase in pitching, the trunk flexes and rotates, initiating the transmission of energy and force to the upper extremity. The nondominant abdominal muscles and lumbar paraspinals activate and aid in pelvic and trunk rotation and flexion. Once the trunk's angular velocity and flexion is increased, more force is generated to permit a faster ball release. Trunk flexion ranges between 32 – 55 degrees, with an angular velocity of 300 – 450 degrees per second (Seroyer *et al.* 2010).

According to Hirashima *et al.* (2008) and Calabrese (2013), the lumbar spine forms a stable base for the throwing action. Trunk rotation and lumbar lateral flexion activates shoulder abduction, thus aiding the arm in reaching a fully cocked position.

In summary, trunk strength is essential when training for ballistic movements which require the transfer of momentum through the kinetic chain and that proximal stability is vital for distal mobility (Chu *et al*. 2013).

According to Young et al. 1996 and Sood (2008), the spine is an important part of the kinematic chain especially in cricket fast bowlers or overhead throwing as it transmits force from the lower to upper limbs as well as it functions as a force generator capable of the accelerating the arm to release the ball, as the glenohumeral joint is incompetent to do it on its own. High ground reaction forces occur during fast bowling in cricketers. The spine absorbs the ground reaction forces from the lower extremities and transfers it up the kinematic chain. Due to the oblique orientation of the facet joints in the thoracic spine it assists by ensuring that the AP forces from the lumbar spine are converted to the more appropriate rotatory forces essential to accelerate the glenohumeral joint (Young *et al* 1996 and Sood 2008).

The lumbar spine provides a level foundation that remains stable during the bowling action. If there is reduced mobility within the lumbar spine this would then potentially result in altered shoulder biomechanics, reduced energy dissipation, and a decrease in the bowling motion (Stuelcken, Ginn and Sinclair 2008).

Therefore, by increasing the mobility and ROM within the thoracic and lumbar spines, would result in an overall increase in trunk mobility, thus resulting in a faster ball release speed (Sood 2008 and Felton *et al.* 2019).

2.6 AN OVERVIEW OF THE THORACIC AND LUMBAR SPINE BONY ANATOMY AND RANGE OF MOTION

2.6.1 Thoracic Spine

The thoracic spine is the longest and most complex region of the spine. The thoracic spine typically consists of 12 consecutive vertebrae (T1-12), it lies in the middle section of the spine, connects to the lumbar spine below and cervical spine above, and runs from the base of the neck to the abdomen (Yezak 2018). The thoracic vertebrae are each made up of the following: one spinous process, a vertebral body, two transverse processes, inferior and superior endplates, a lamina, and two pedicles. The thoracic vertebrae are divided in typical and atypical (T2-T8).

The characteristic features of the typical thoracic vertebrae are as follows (Moore, Dalley and Agur 2010):

- Costal facets – primary feature, for articulation with the ribs.
- Vertebral body – is heart shaped and has costal facets. Due to the orientation of the vertebrae the thoracic spine absorbs most of the pressure and stresses.
- Vertebral arch – forms much of the spinal canal laterally and posteriorly.
- Spinal canal – is circular and smaller than those in the lumbar and cervical spine.
- Facet joints – lie near and posterior to vertebral arch and have superior and inferior facets which articulate with the adjacent vertebrae.
- Costovertebral joints – points at which the ribs and vertebrae articulate.

- Transverse processes – long, sturdy and extend posterior laterally. The length decreases from T1-T12.
- Articular processes – the superior facets lie posterior and slightly laterally and inferior facets lie anterior and slightly medially.
- Spinous processes – long, slope posteroinferiorly and extend to the vertebrae below.
- The thoracic vertebrae join to form a kyphotic curve, which curves outwards to allow more room for the internal organs (heart and lungs).

The thoracic spine articulations consist of the intervertebral disc, a pair of zygapophyseal and costovertebral joints.

The vertebral column has 23 intervertebral discs, and 12 of those discs are present in the thoracic portion of the spine. The disc lies between two adjacent vertebrae to provide shock absorption, cushioning and prevent grinding of the vertebrae. According to Yezak (2018), the thoracic discs are thinner than those of the cervical and lumbar regions, thus contributing to the limitation in movement when compared to the lumbar and cervical spine.

The costovertebral joints are the site at which the vertebrae and ribs articulate. These are divided into two categories (Yezak 2018):

- Costocorporeal joint – the rib head joins with two adjacent vertebral bodies and the IVD. The inferior portion of the vertebra above and the superior portion of the vertebra below have a costal demi-facet each, which form a full costal facet to permit articulation between the rib head and vertebrae.
- Costotransverse joint – these joints permit the articulation between the transverse process and the tubercle of the rib head.

The facet joints are synovial in nature and lie between the inferior articular process of the vertebra above and superior articular process of the vertebra below. The primary function of the facet joint is to transmit loads, and guide and limit motions due to its geometric and mechanical function. The superior facet is flat and faces posteriorly, superiorly, and laterally, while the inferior facet is concave and faces anteriorly, inferiorly, and medially. The facets in the thoracic spine are angled at 60° to the transverse plane and 20° to the frontal plane (Jaumard, Welch and Winkelstein 2011).

Moore, Dalley and Agur (2010) reported that the thoracic spine consists of three muscular layers: superficial (thoracolumbar fascia), intermediate (iliocostalis, longissimus and spinalis), and deep (semispinalis, multifidus and rotatores).

The principal movements of the thoracic spine are aided by the following muscles (Moore, Dalley and Agur 2010):

- Flexion – bilateral action of the rectus abdominus and psoas major.
- Extension – bilateral action of the erector spinae, multifidus, and semispinalis thoracis.
- Lateral flexion – unilateral action of, the iliocostalis and longissimus thoracis, multifidus, external and internal oblique, rhomboids, and serratus anterior.
- Rotation – unilateral action of the external obliques, splenius thoracis, iliocostalis and longissimus thoracis.

The thoracic spine consists of 12 nerve roots (T1-T12) that emerge from the spinal cord laterally and innervate the upper back, chest, and abdomen. The nerve roots exit through the intervertebral foramina (IVF). The nerve root is named according to the vertebra that lies above it (e.g. T3 nerve root exits between T3 and T4 vertebrae). Once the nerve exits from the IVF, it branches into two different nerve bundles and joins the ventral (anterior) and dorsal (posterior) ramus of the body. T1-T11 ventral rami develop into the intercostal nerve and follow a similar route as the ribs. T12 ventral rami develops into a subcostal nerve and travels below the 12^{th} rib. Dorsal rami T1-T12 go into the back muscles and provide sensation to the skin (Yezak 2018).

The motor and sensory functions of the thoracic nerves are as follows (Yezak 2018):

- **T1 and T2** – provide sensation to the arm, hand, and superior chest wall.
- **T3, T4 and T5** – feeds into the chest wall and assists with breathing.

- **T6, T7, and T8** – provides sensation to the chest wall and abdomen.
- **T9, T10, T11 and T12** – feeds into the abdomen and lower back.

According to Liebsch and Wilke (2018), the main functions of the thoracic spine are to protect the spinal cord, anchor the rib cage, provide stability and balance for the sagittal plane of the spine together with the abdominal muscles and erector spinae, transmit loads from the superior aspects to the inferior spinal regions and achieve adequate flexibility during 3-dimensional range of motion. According to Yezak (2018), the thoracic vertebrae form the foundation of the thoracic spine's strong spinal column which supports the neck above, the rib cage, soft tissues, blood vessels, nerves and joints.

Yezak (2018) postulated that the thoracic spine has limited range of motion in comparison to the cervical and lumbar spine. However, the ranges of motion differ at different thoracic vertebral levels. Most of the thoracic spine limits flexion, extension, and lateral flexion. However, rotatory movements are permitted. The lower thoracic vertebrae (T9-T12) are like the lumbar vertebrae, and thus flexion, extension and lateral rotation are permitted, while axial rotation is limited. The limitation in movement is entirely due to the anchoring of the rib cage and the attachment of the ribs.

Table 2.2 shows the estimated normal ranges of motion in the thoracic spine (Williams 2017; Geelhoed *et al.* (2006).

Table 2.2: Estimated normal ranges of motion in the thoracic spine (Williams 2017)

Range of Motion	Degrees
Rotation	>30
Kyphosis	50
Flexion	20 – 45
Extension	25 – 45
Lateral flexion	20 – 40

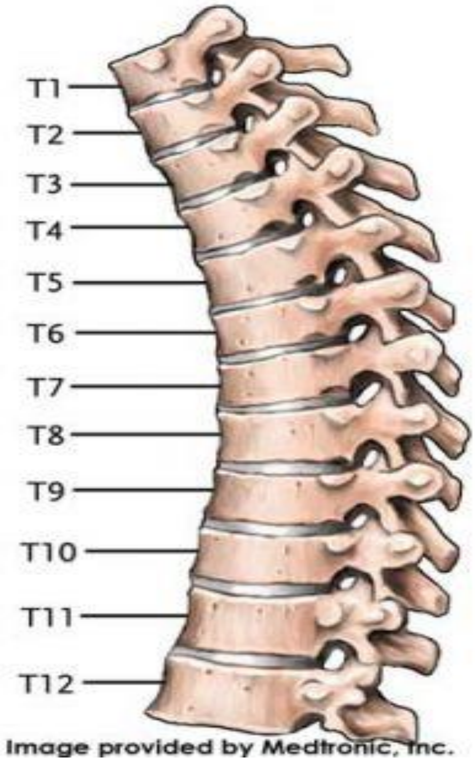


Figure 2.5: The thoracic spine T1 -T12 (Spine 2017)

2.6.2 Lumbar spine

According to Moore, Dalley and Agur 2010, the lumbar spine classically comprises of five consecutive vertebrae (L1-5). The lumbar vertebrae are made up of the following structures: a vertebral body, a spinous process, two transverse processes, inferior and superior endplates, a lamina and two pedicles.

Each lumbar vertebra has two sections: the neural vertebral body and neural arch. The vertebral body lies anteriorly, and it gradually increases in size from superior to inferior. The neural arch lies posterior to the vertebral body and has a pair of pedicles emerging from the posterolateral aspect of the superior portion of the vertebral body, joining the lamina on either side. The characteristic features of the lumbar spine are described below:

- The vertebral body is wider horizontally and is kidney shaped. The vertebrae join to form a lordotic curve.
- No transverse foramen and costal facets.

- The spinal canal through which the spinal nerve passes is triangular and larger than in the thoracic spine, but smaller than in the cervical spine.
- The transverse processes are long and slim.
- Spinous processes are short, strong, thick, broad and hatchet shaped.
- The pedicles are short, have a slight medial inclination, and increase in width from L1-5.
- The laminae are broad and directed vertically in the sagittal plane. They are divided into two portions: cephalic and caudal. The cephalic portion is the smooth inner surface, and the caudal is the rough outer surface to which the ligamentum flavum attaches.
- The superior endplate is concave, faces posteromedial and consists of mamillary processes.
- The inferior endplate is convex and faces anterolaterally.

The lumbar spine articulations consist of a pair of zygapophyseal joints (facet joints) and an intervertebral disc. The intervertebral disc (IVD) is avascular, lies medially between two adjacent vertebral bodies, permits flexion, lateral flexion and extension and is an excellent shock absorber. The IVD comprises of a gelatinous central mass, called the nucleus pulposus, a fibrous outer layer composed of fibrocartilage, called the annulus fibrosus, and cartilaginous endplates (Ebraheim *et al.* 2004; Moore, Dalley and Agur 2010).

The facet joints comprise of the superior and inferior articular processes and the articular capsule. The articular surface is covered by hyaline cartilage, thus permitting the sliding movement. The articular capsules are thin and have an outer fibrosus and inner synovial membrane (Moore, Dalley and Agur 2010).

There are many ligaments that play a vital role in the stabilization of the spine; these are (Moore, Dalley, Agur 2010):

- Anterior longitudinal – this is a strong band that attaches through the entire anterior portion of the vertebral body and IVD, from the skull to the sacrum. The anterior medial part is thick, while the anterior lateral aspect is thin. Its main function is to limit extension of the spinal column (Ebraheim *et al.* 2004).

- Posterior longitudinal attach from the posterior portion of the occipital bone to the sacrum. In the cervical spine, it is thick and uniform, while in the thoracic and lumbar spine, it is broader over the IVD and narrower over the middle of the vertebral body. Its main function is to stabilize the spinal column during flexion (Moore, Dalley and Agur 2010).
- Ligamentum flavum are paired ligaments that lie between adjacent vertebral bodies and fuse centrally. These are comprised of yellow elastic fibres and they are very thick in the lumbar spine. The lumbar ligamentum flavum consists of two layers: superficial and deep (Ebraheim *et al.* 2004).
- The supraspinous and interspinous ligaments lie posteriorly and link the spinous processes to one another. The interspinous ligament is slim and spreads from the lower portion of one spinous process to the upper portion of the other. The supraspinous ligaments are sturdier and spread over all spinous processes from the occipital bone to the sacrum (Ebraheim *et al.* 2004).

The spinal nerves comprise of the dorsal and ventral roots, which enter and leave the spinal column. Ali and Dublin 2020 stated that the dorsal roots are comprised of sensory axons which arise from the sensory cell bodies confined in the ganglia, while the ventral roots are comprised of motor neurons from the anterior grey horn of the spinal cord. The lumbar region has 11 pairs of spinal nerves: five lumbar, five sacral and one coccygeal. The spinal nerves emerge from the vertebra below. Upon exiting through the intervertebral foramina, they divide into small dorsal rami and one large ventral ramus. The dorsal rami run posteriorly and supply the spinal muscles, ligaments, and the skin. The ventral rami are long and run inferolateral in the lumbar portion to form the lumbar sacral plexus, which supplies the muscles, joints and skin of the upper and lower extremity (Ali and Dublin 2020.

Moore, Dalley and Agur (2010) postulated that the lumbar spine has three layers of muscles:

- Superficial layer – thoracolumbar fascia.
- Intermediate layer – erector spinae. The erector spinae lie in a groove on either side of the vertebral column amid the spinous processes centrally and the ribs laterally. It is divided into three layers: iliocostalis (lateral layer), longissimus (intermediate layer) and spinalis (medial layer). The main function of the erector spinae is to extend the vertebral column when acting bilaterally, however, it flexes the vertebral column when acting unilaterally (Moore, Dalley and Agur 2010).
- Deep layer – transversospinalis. These muscles lie deep to the erector spinae. They comprise of the semispinalis (superficial layer), multifidus (middle layer) and rotatores (deep layer). The semispinalis muscle extends the lumbar spine, multifidus stabilizes the lumbar spine and the rotatores stabilizes, and assists with local extension and rotatory motions of the vertebral column (Moore, Dalley and Agur 2010).

The primary movements of the lumbar spine are flexion, extension, lateral flexion, and rotation. The erector spinae muscles (iliocostalis, longissimus and spinals) permit and stabilize the spine during ranges of motion. **Table 2.3** shows the estimated normal lumbar range of motion.

Table 2.3: Estimated normal lumbar range of motion (Williams 2017)

Range of Motion	Degrees
Flexion	>60
Extension	>25
Lateral flexion	>25 – 30
Rotation	5 – 10

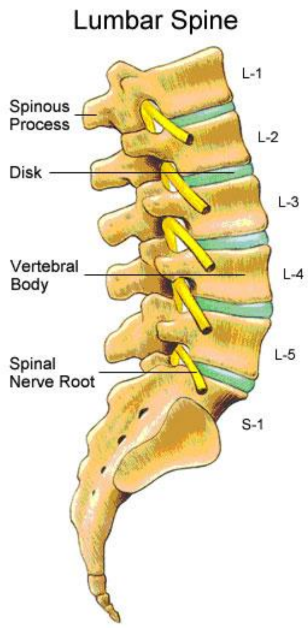


Figure 2.6: The lumbar spine (lateral view) (Moore, Dalley and Agur 2010)

2.7 CHIROPRACTIC SPINAL MANIPULATION AND RANGE OF MOTION

2.7.1 Chiropractic

Chiropractic is a complementary and alternative medicine occupation that has been successful in achieving the formal criteria of a profession. Irrespective of this, chiropractic is disregarded from the public health care system, but it continues to improve its position (Brosnan 2017).

Chiropractic is a healing art which focuses on the function of the spine and spinal cord encased within it. When the spine is aligned properly, the hard-bony shell protects the spinal cord from damage while the vertebral body provides flexibility and stability. When the vertebral body is out of place, a subluxation (misalignment of the spinal cord) occurs. This results in pain and reduced functioning of the nervous system, which is required to co-ordinate the musculoskeletal system (Hoiriis *et al.* 2004).

Chiropractors are medical professionals who specialize in the management and treatment of all people, including athletes. Chiropractors specialize in the management and treatment of neuromusculoskeletal conditions. Just as an unstable foundation of a home can result in its collapse, the spine and pelvis serve as the body's foundation. If there are any fixations in these structures, the human body is unable to function optimally. A subluxation can have a profound effect on how the central nervous system (CNS) communicates with the brain. A subluxation can affect an individual's performance. If the subluxation occurs in the area around the shoulder, then there will be differences in muscle firing (concentric muscle activation; when the muscle shortens) and thus in throwing, athletes (cricket bowlers or baseball pitchers) performance will be diminished (Hoiriis *et al.* 2004). A chiropractor's job is to correct the subluxation. When the subluxation is corrected, pain is decreased; sleep, activity and mood are improved.

2.7.2 Motion Palpation

Motion palpation is a procedure whereby a physician introduces motion to the joint to determine the maximum range of motion and identify any restrictions. This technique is employed by physicians to detect a restricted joint prior to manipulation (Cooperstein, Haneline and Young 2010).

2.7.3 Spinal Manipulation

Spinal manipulative therapy is a form of manual therapy which involves moving the joint past the end range of motion, but not past the paraphysiological zone (anatomical range of motion). The movement of the joint may be followed by an audible "crack" or "pop". Many researchers now believe that the crack or pop occurs from the formation of bubbles. Kawchuk *et al.* (2015) the lead author of a 2015 study, reported that bubbles form as the joint surfaces separate because there is not sufficient joint fluid to fill the enlarged space, and therefore a gas-filled cavity is created, and this is associated with the audible crack or pop. Applying pressure on a joint might also cause the oxygen, nitrogen and carbon dioxide gases present between joints to release (Kawchuk *et al.* 2015). Another theory is that when the joint surfaces separate, synovial fluid rushes in to fill the gap. The influx of fluid is what makes the noise and creates a sensation when a joint is popped (Kawchuk *et al.* 2015).

Triano (2001) and Deyo (2017) stated that spinal manipulative therapy (SMT) has been practiced since ancient years in the treatment of low back pain. Hippocrates, the father of medicine, was familiar in using SMT (Callender and Wiese 2005). Gatterman (2004) defined manipulation as a passive manual method which is applied to the vertebrae with the aim of restoring mobility to the subluxation (restricted area) and to increase range of motion. Jermyn (2004) emphasised that 30-40% of individuals with acute neck and low back pain use SMT as their main treatment option. Mechanical strain on the intervertebral joint acts as a barrier to normal full range of motion; the primary use of manipulation is to reverse this mechanical strain (Jermyn 2004 and Rubinstein *et al.* 2011)

The biomechanical changes caused by SMT are said to have physiological consequences by affecting the inflow of sensory information to the CNS. The biomechanical changes that occur in the vertebral column are reported to affect the neural input, and later altering central processing and affecting reflex somatovisceral or somatomotor output. Spinal manipulation induces changes in the neuromusculoskeletal systems. Evidence specifies that the impulse load from spinal manipulation impacts proprioceptive primary afferent neurons from paraspinal tissues. In addition, spinal manipulation can affect pain processing, possibly by changing the central facilitated state of the spinal cord, and it can also affect the motor control system (Hadler *et al.* 2007).

The golgi tendon organs and muscle spindles are stimulated by SMT. Individuals with a herniated disc will show clinical improvement after SMT. Numerous studies show that SMT increases pain tolerance and can alter central sensory processing by removing the chemical stimuli from the paraspinal tissues. SMT also affects reflex neutral outputs (muscle spindles and golgi tendon organs) and evokes paraspinal muscle reflexes and alters motor neuron excitability (Pickar 2002).

Many scientists and clinicians have long reported that spinal manipulation utilizes its biologic effects on segmental components of the central nervous system (Howell *et al.* 2006; Clark *et al.* 2009). It has been suggested that manual therapies act through a cascade of neurophysiologic responses to reduce muscle spasm and subsequent pain (Pickar 2002).

Nook and Nook (2011) reported that the basis and definition of chiropractic emphasizes the correction of pathomechanics of the joints in the spine and extremities, and thus restoring normal neurology and biomechanics. They further stated that restoration of the pathomechanical faults will decrease pain, injury severity and possibly enhance performance.

Spinal manipulation has been shown by several authors to positively influence athletes' performance (Costa *et al.* 2009; Humphiries *et al.* 2013). Studies in the Journal of Chiropractic Research and Clinical Investigation by Miners (2010), Jarosz and Elliot (2010) and Costa *et al.* (2009) reported that athletes who received chiropractic care exhibited up to 30% increase in athletic ability after treatment. Miners (2010) and Jarosz and Elliot (2010) stated that after spinal and knee manipulation an elite racewalker broke his personal records. Costa *et al.* (2009) postulated that spinal manipulation with muscle strengthening was associated with an improvement in full swing performance in golfers.

According to Kamali, Sinaei and Bahadorian (2017) spinal manipulative therapy can positively influence both asymptomatic and symptomatic athletes. The effects of the manipulative therapy may occur immediately, while it could also be used as a repetitive treatment protocol to reduce pain and enhance performance.

Miners (2010) stated that chiropractic truly excels in its ability to improve performance, since peak performance is achieved through the full use of the central nervous system (CNS). He further reported that chiropractic is the only form of care to deliver 100% nerve flow and peak performance. Miners (2010) furthered emphasized that a chiropractor may become the most important health care provider to the athlete because the correction of the subluxation is key to improving health, and performance.

Miners (2010) specified that it did not necessarily matter if an athlete were asymptomatic or healthy, they could still benefit from chiropractic care to optimize their health and maximize performance. Miners (2010) stated that when athletes were adjusted before they competed, many had improved performances and broke personal records.

In Canada, the research teams included chiropractic care into the rehabilitation program of injured female long-distance runners; this resulted in a significant increase in their overall performance (Kelly *et al.* 2000). Similarly, in New Zealand, SMT was tested to assess its effects on reaction time. Individuals who received cervical spine manipulation had a faster reaction time in comparison to those who had rested (Kelly *et al.* 2000).

Chiropractic adjustments improve healing time, reaction time and coordination (DeVocht *et al*. 2016). Chiropractic and SMT not only enhance performance but also keep athletes in the field of sport for longer (Hoskins and Pollard 2010). Hadler *et al.* (2007) found SMT to be superior to mobilisation, diathermy, patient education and placebo approaches. Patients who received SMT recovered quicker than those who received diathermy, exercise, ergonomic instructions and/or placebo interventions.

Spinal manipulative therapy has been progressively utilized in sports and has been revealed to be a useful therapeutic strategy for biomechanical joint dysfunction, especially involving the spine (Konczak 2010). Several neurophysiological effects have been described (Pickar 2002), but the unifying physiological mechanism is still not clear.

Electromyographic movement is generally reduced in latent muscles after SMT (DeVocht, Pickar and Wilder 2005) and increased at isometric contraction (Keller and Colloca 2000). Corticospinal excitability is usually improved, with some exclusions. Increased muscle strength, decreased muscle inhibition, and muscle fatigue inhibition were detected, as were lesser levels of pro-inflammatory cytokines and pain perception in humans and animals (Botelho and Andrade 2012). These variations could interfere with sports performance; however, there is still partial evidence to support SMT's ability to improve sports performance (Schwartzbauer 2013a).

2.7.4 Spinal Manipulation Effect on Trunk Range of Motion

Several authors found that spinal manipulative therapy (SMT) improved range of motion in participants symptomatic of low back pain. Post SMT participants with low back pain showed an increase in lumbar motion when compared to initial measurements (Chul-ho, Minjeong and Gi Duck 2015)

Millan *et al.* (2012) reported that the biomechanical effect of SMT is influenced by a decrease in pain. Therefore, by reducing pain in symptomatic participants, an increase in trunk motion is possible.

Thomas *et al.* (2011) stated that many overhead throwing athletes (such as bowling, pitching, javelin throwing, etc.) produce excessive amounts of shoulder external rotation with limited shoulder internal rotation at 90 degrees of abduction in the throwing. Eccentric shoulder muscle contraction causes a rise in muscle tension, and thus reducing active range of motion within the shoulder joint. The thoracic spine has a predominantly close relationship with the shoulder complex, due to the scapulothoracic joint, and various muscle attachments between the spine and the shoulder (Moore, Dalley and Agur 2010). Therefore, muscular tension within the shoulder will influence the range of motion within the thoracic spine (Stuelcken, Ginn and Sinclair 2008). Engel, Dawe, and Edwards (2017) reported that post SMT trunk motion in flatwater sprint kayaking paddlers increased significantly.

Engel, Dawe, and Edwards (2017) postulated the following theories as explanations for the increase in range of motion:

- A change in the orientation and/or positioning of several anatomical structures.
- Increased range of motion of motion segments
- Increasing neurological input.
- Unbuckling of ligaments and the release of trapped meniscoids.
- Breaking of adhesions.
- Return of normal motion segment function.

Kriel (2004); Sood (2008); Deutschmann (2015) and Robson (2018) used SMT and sham therapy to assess the effectiveness of mechanical therapy versus psychological therapy on chest wall expansion, bowling speed, kicking speed and range of motion.

2.8 PLACEBO EFFECTS

2.8.1 Placebo Effect

A placebo (sham therapy) is used in clinical trials to assess the effectiveness of treatment versus non-treatment. A placebo has a psychological effect on an individual (Draper 2002, Sood 2008; Deutschmann 2015; Ruddock *et al.* 2016).

The randomised controlled trial (RCT) concept allows researchers to assess if a cause-effect relationship exists by assessing whether the participants who receive treatment under investigation improve more frequently and rapidly, compared to those without treatment or with alternative treatment. A placebo-controlled randomised controlled trial is utilised when the researcher accounts for the non-specific treatment effects that are not dependent on the intervention (Puhl *et al.* 2017).

According to Puhl *et al.* (2017), a placebo-controlled RCT is dependent on a control intervention that would account for the non-specific treatment effects which have no specific benefits from the actual intervention. Reliability is essential in a placebo-controlled RCT and it is important that participants are blinded to the fact that the intervention has no therapeutic effect, and thus permitting accurate assessment and interpretation of the trial results (Puhl *et al.* 2017).

Studies indicate that spinal manipulation is superior to placebo manipulation in the enhancement and treatment of athletes and non-specific low back pain.

Hancock *et al.* (2006) suggested that the most effective placebo manipulation was Maitland’s log-roll. The patient would lie in a side-lying position, while the researcher’s hand is placed over the Participant’s ilium and ribs. The trunk and pelvis are rolled together so no intervertebral motion occurs. Maitland is an author that explained vertebral manipulation techniques as well as the different mobilisation and placebo techniques.

2.9 CONCLUSION

With bowling speed being so important and the outcome of a game of cricket being dependant on proper execution of fast bowlers (Seroyer *et al.* 2010), it may be said that bowlers should be performing this routine action at their maximum potential every time they bowl a ball. Due to its open biomechanical nature, the bowling action is a direct result of a summary of forces formed by the muscles of the body, as well as the momentum created by the trunk, joint and limb movements (Seroyer *et al.* 2010).

Humphiries *et al.* (2013) assessed the immediate effect of cervical spine manipulation on handgrip strength and free throw accuracy in asymptomatic basketball players. There was a significant increase in free throwing, and a marginal improvement in handgrip strength. The results from that study preliminary show that a single cervical spine manipulation positively influenced the handgrip strength and free throw accuracy in athletes, and therefore the researcher proposed a study to determine if spinal manipulation may impact the bowling speed in elite male and female cricketers.

Studies conducted by Sood (2008), Deutschmann (2015) and Robson (2018), on asymptomatic participants, showed a significant increase in both lumbar spine range of motion and thoracic spine range of motion post spinal manipulation. However, the above authors did not assess all the ranges of motion, therefore the aim of this study is to assess whether spinal manipulation can enhance thoracic and lumbar range of motion, and bowling speed.

Based on the postulations made by Zheng *et al.* (2008b) and Chu *et al.* (2009) on the similarities and differences in the kinematics in male and females and the findings of Sood (2008), Deutschmann (2015) and Robson (2018) on changes in range of motion, the researcher proposed this study to assess whether lumbar spine manipulation, thoracic spine manipulation and placebo spinal manipulation will influence the range of motion and bowling speed in elite male and female cricket bowlers.

CHAPTER THREE: METHODOLOGY

3.1 STUDY DESIGN

This was a quantitative study, using a pre-test and post-test design.

3.2 STUDY POPULATION

The participants included in this study comprised of 60 asymptomatic male and female indoor cricket bowlers from the Durban area, between the ages of 18-40 years which were divided into three groups.

3.3 STUDY LOCATION

The study was conducted off-campus at Sahara Stadium Kingsmead and The Chatsworth Cricket Oval with supervision from a qualified clinician.

3.4 PERMISSIONS

Permissions to use the cricket arenas were obtained (**Appendix H**) for this study.

3.5 ADVERTISING

Advertisements (**Appendix A)** were placed at local malls, cricketing arenas, campuses, schools, and gyms to maximize the exposure of this study. Emails and word-of-mouth advertising were also be implemented. Emails were sent to the KZN Cricket Union, local cricketing clubs and schools. Potential participants were requested to contact the researcher telephonically or via email for more information. Participation was voluntary and without remuneration.

3.6 RECRUITMENT

The participants, who responded to the adverts (Appendix A) telephonically or via email, were asked the following questions to determine their inclusion in the study:

2.1. Do you have a few minutes to answer some questions? (Yes/No)

2.2. Are you between the ages of 18-40 years?

2.3. Are you a cricketer? (Yes/No)

2.4. Do you bat, bowl or are you an all-rounder?

2.5. Are you on treatment for any medical condition? (Yes/No)

2.6. Have you been playing for more than three months? (Yes/No)

Questions 1, 3, 5, and 6 were yes or no questions. Questions 2 and 4 were specific, for which the participants needed to elaborate on their responses. Participants who responded as being bowlers and all-rounders were included in this study. Participants had to be within the age range of 18-40 years old, and not on treatment for any medical condition. Participants must have been playing cricket for at least three months (these players would know the correct technique for bowling).

3.7 SAMPLE SIZE

Power analysis for a one-way ANOVA with three groups was conducted in G*Power to determine a sufficient sample size using an alpha of 0.05, a power of 0.80, and a large effect size (f = 0.40) (Singh, 2017). A sample size of 60 asymptomatic participants was used in this study. Participants were recruited through convenience sampling and were randomly divided into three groups (each consisting of 10 participants) using the hat method. Numbers 1, 2 and 3 were written on pieces of paper and placed in an envelope and each participant was requested to pick a piece of paper from the envelope to determine their group allocation. Group one received a thoracic spine manipulation, Group two a lumbar spine manipulation and

Group three a placebo spinal manipulation (which is further explained under group allocation) (Singh 2017).

3.8 CONSULTATION

Consultations were held at Sahara Stadium Kingsmead and Chatsworth Cricket Oval after permission to use these premises were obtained (**Appendix H and I**). For the consultations being held at the arena, the treatment area was curtained-off to provide privacy to the participant. The entire research protocol was explained in detail by the researcher to every potential participant. The participants were verbally informed and received an Information Letter (**Appendix B**) which explained the aims, rules, and regulations of the study. The participants then signed an Informed Consent Form (**Appendix C**) stating that they had been informed about the research topic and were willing to be part of the study.

At the consultation, each potential participant had undergone a mandatory case history (**Appendix D**), physical examination (**Appendix E**), and relevant lumbar and thoracic spine orthopaedic examinations (**Appendix F and G**) were performed to assess the participant's eligibility for the study which was all supervised by a qualified practitioner.

3.8.1 Inclusion Criteria

- Participants had to be indoor cricketers between the ages of 18-40 years.
- Participants had to be indoor cricket bowlers with no clinical musculoskeletal symptoms. Case history, physical exam and past medical records assisted in determining if the participant was healthy and asymptomatic.
- Participants had to have read and signed the study and informed consent (**Appendix C**).
- Participants had to be playing cricket for a minimum of 3 months.
- Participants had to be playing cricket at either school, club, provincial or national level and registered with the KZNCU.

3.8.2 Exclusion Criteria

- Participants who had any contraindications to spinal manipulation, i.e. fractures, degenerative or cardiovascular diseases (hypertension, arrhythmia).
- Participants who had spinal abnormalities, cauda equina syndrome, stress fractures, structural abnormalities, leg length inequality, and chronic illnesses. Taking of a thorough case history, past medical history, physical exam, and orthopaedic exam assisted in identifying the presence of the above conditions.
- Participants who were pregnant, due to the increased stress and strain on the participant. Also, if any accidents occurred during the study this could have harmed either mother or child.
- Participants who had a positive sciatic nerve test and or signs of paraesthesia after completion of the orthopaedic and neurological tests, as this would indicate that the participant had a neurological condition or a nerve root entrapment. Therefore, participation in this study would have aggravated the condition.

3.8.3 Participant Informed Consent

The participant was given an Informed Consent Form (**Appendix C**) after agreeing to participate in the study (after reading the participant information sheet included in **Appendix B**, and verbal explanation of the study by the researcher).

3.8.4 Group Allocation

Once the informed consent was signed, the participants were randomly allocated to one of three groups. In an envelope there were three pieces of paper (with a 1, 2, and 3 written on them). Each participant had to draw a piece of paper from the envelope. Those participants who drew 1 were placed in Group 1a (males) or Group 1b (females) and received a thoracic spine manipulation. Those who drew 2 were placed in Group 2a (males) or Group 2b (females) and received a lumbar spine manipulation and those who drew 3 were placed in Group 3a (males) or Group 3b (females) and received a placebo spinal manipulation.

3.9 PROCEDURE

A case history (important and relevant information of the participant), physical examination (to rule out systemic conditions) and lumbar and thoracic regional examinations (to rule out neurological conditions) were conducted prior to the warm-up.

3.9.1 Warm-Up

Each participant was instructed to do warm up exercises for five minutes (**Appendix O**) prior to bowling, to ensure that the muscles were adequately stretched.

3.9.2 Assessment and Measurement of Range of Motion of the Thoracic and Lumbar spine

Flexion of the thoracic spine – the participant was seated in an anatomically upright position. A mark was made at the midpoint of the thoracic spine, at the level of spinous process T6. The inclinometer was placed at the level of T6 and strapped around the Participant's bowling arm. The inclinometer was switched on and placed at zero (0). The researcher demonstrated how to forward flex the trunk; the participant had to forward flex his/her trunk. The inclinometer had to be stable during the movement. Once the flexion limit was met, it was recorded. The participant had to then return to the neutral position (Sood 2008).

Extension of the thoracic spine – from the upright seated neutral position, the researcher demonstrated how to extend the trunk; the participant had to then extend his/her trunk. The inclinometer was stable during the movement. Once the extension limit was met, it was recorded. The participant had to then return to the neutral position (Sood 2008).

Rotation of the thoracic spine – from the upright seated neutral position, the researcher demonstrated how to rotate the trunk; the participant had to then rotate his/her trunk (right). The inclinometer was stable during the movement. Once the maximum rotation was reached, it was recorded. The participant had to then return to the neutral position and then repeat the same movement on the opposite (left) side (Sood 2008).

Lateral flexion of the thoracic spine – from the upright seated neutral posture, the participant had to laterally flex his/her body to the right without moving the legs. This movement was demonstrated to the participant. The inclinometer was set to zero (0) and stable. The participant had to then laterally flex. Once maximum lateral flexion was reached, a reading was taken; this indicated the degree of lateral flexion. The participant had to then straighten up, return to the neutral position and then repeat the same movement on the opposite (left) side (Sood 2008).

Flexion of the lumbar spine - the participant was advised to stand upright; a mark was made between L2 and L3 (lumbar vertebrae), and this was used as the midpoint of the lumbar spine. The sensor of the inclinometer was placed at the above-mentioned point and it was strapped around the participant's waist. The inclinometer was switched on and set to zero (0). Once the meter was set and stable, the participant had to then forward flex as far as possible without bending at the knees. Once maximum flexion was reached, a reading was taken; this was the degree of flexion. The participant had to then return to the neutral position (Sood 2008).

Extension of the lumbar spine –from the upright neutral position, the researcher demonstrated how to extend the trunk; the participant had to then extend his/her trunk without bending at the knees. The inclinometer was stable during the movement. Once the extension limit was met, it was recorded. The participant had to then return to the neutral position (Sood 2008).

Rotation of the lumbar spine - from the upright neutral position, the researcher demonstrated how to rotate the trunk; the participant had to then rotate his/her trunk (right). The inclinometer was stable during the movement. Once the maximum rotation was reached, it was recorded. The participant had to then return to the neutral position and then repeat the same movement on the opposite (left) side (Sood 2008).

Lateral flexion of the lumbar spine – from the neutral position, the participant had to laterally flex his/her trunk to the right without bending at the knees; this was demonstrated by the researcher first. The inclinometer was set at zero (0). Once the lateral flexion limit had been reached, a reading was taken; this was the maximum degree of lateral flexion. The participant had to then return to the neutral position and repeat the same movement on the opposite (left) side (Sood 2008).

On completion of the initial range of motion findings as stated above, the bowling speed measurement was recorded, followed by the spinal manipulations (as allocated by the groups) and thereafter spinal range of motion and bowling speed was re-assessed.

The Saunders digital inclinometer was used to determine and measure the spinal range of motion. The measurements were conducted prior to bowling speed but after the completion of the physical exams. The ROM for a specific segment was not measured, but the change in T/S and L/S.

3.9.3 Bowling

The following instructions were given to each participant before bowling:

- The run-up distance had to be 1m.
- One delivery should be bowled.

To ensure the participant’s natural bowling technique was not altered, the angle of the run-up was not specified.

Thereafter, the bowling speed was measured and recorded using the SpeedTrac Radar machine.

3.9.4 Manipulative Techniques

Once the range of motion and bowling speed were measured, one of the following manipulative techniques were applied to the participant:

Table 3.1. Tabulating the Interventions

Group 1a and Group 1b Experimental Group	Group 2a and Group 2b Experimental Group	Group 3a and Group 3b Control Group
This group received a high velocity low amplitude manipulation to the mid-lower thoracic spine (T6-T8). The manipulation was done in a prone position; the researcher applied a hypothenar contact over the respective levels.	This group received a high velocity low amplitude manipulation to the lumbar spine (L2-3) in the specific direction of restriction. The manipulation was done in a seated position; the researcher utilized the pisiform transverse process (TVP) contact method.	A sham therapy was applied to assess if the change was due to mechanical effect or psychological effect (Participant's perception). A placebo spinal manipulation was conducted with the Participant prone and the researcher contacted over the TVP's of the lumbar spine.

The range of motions of the thoracic and lumbar spines were measured once again using the digital inclinometer. This was done immediately after the respective interventions. The bowling speed was measured again, immediately after the inclinometer assessment. The final assessment was participants' perception of whether there was a change in their bowling speed (**Appendix L**).

3.9.5 The Need for a Control Group

A placebo is a sham therapy that is used when a researcher needs to assess the effectiveness of a procedure. The placebo effect is known to alter results that are obtained in studies in which a participant's performance is being measured. To minimize this effect, a control group had to be included in this study; this was Group 3. The utilization of the sham therapy was to assess whether the outcome of the study was influenced by a mechanical effect or a psychological effect (Bialosky, Bishop and Robinson 2011)

.

The Placebo Spinal Manipulation

A participant was instructed to be in a prone position. The participant had his/her back area exposed while the researcher contacted an area over the thoracic and lumbar spine without applying a manipulative technique or thrust.

3.9.6 The Outcome Measures

- Range of motion of the lumbar spine in flexion, extension, lateral flexion, and rotation measured pre-and post-intervention.
- Range of motion of the thoracic spine in flexion, extension, lateral flexion, and rotation measured pre-and post-intervention.
- Bowling speed was measured using the SpeedTrac Radar (km/h).
- The participants' perception of bowling speed pre-intervention and post-intervention (Appendix J).

3.10 MEASUREMENT TOOLS

3.10.1 Objective Measurements

3.10.1.1 Digital Inclinometer

A baseline digital inclinometer is used by chiropractors, physical therapists, and researchers to determine the range of motion for a patient or to test a participant. A digital inclinometer consists of two Velcro straps, an on/off button, a hold button, digital sensor, and an alternate zero button. If the sensor is tilted 10 degrees, then it will read 10 degrees. However, if it was zeroed at 10 degrees and then tilted to 30 degrees, it will read 30 degrees.

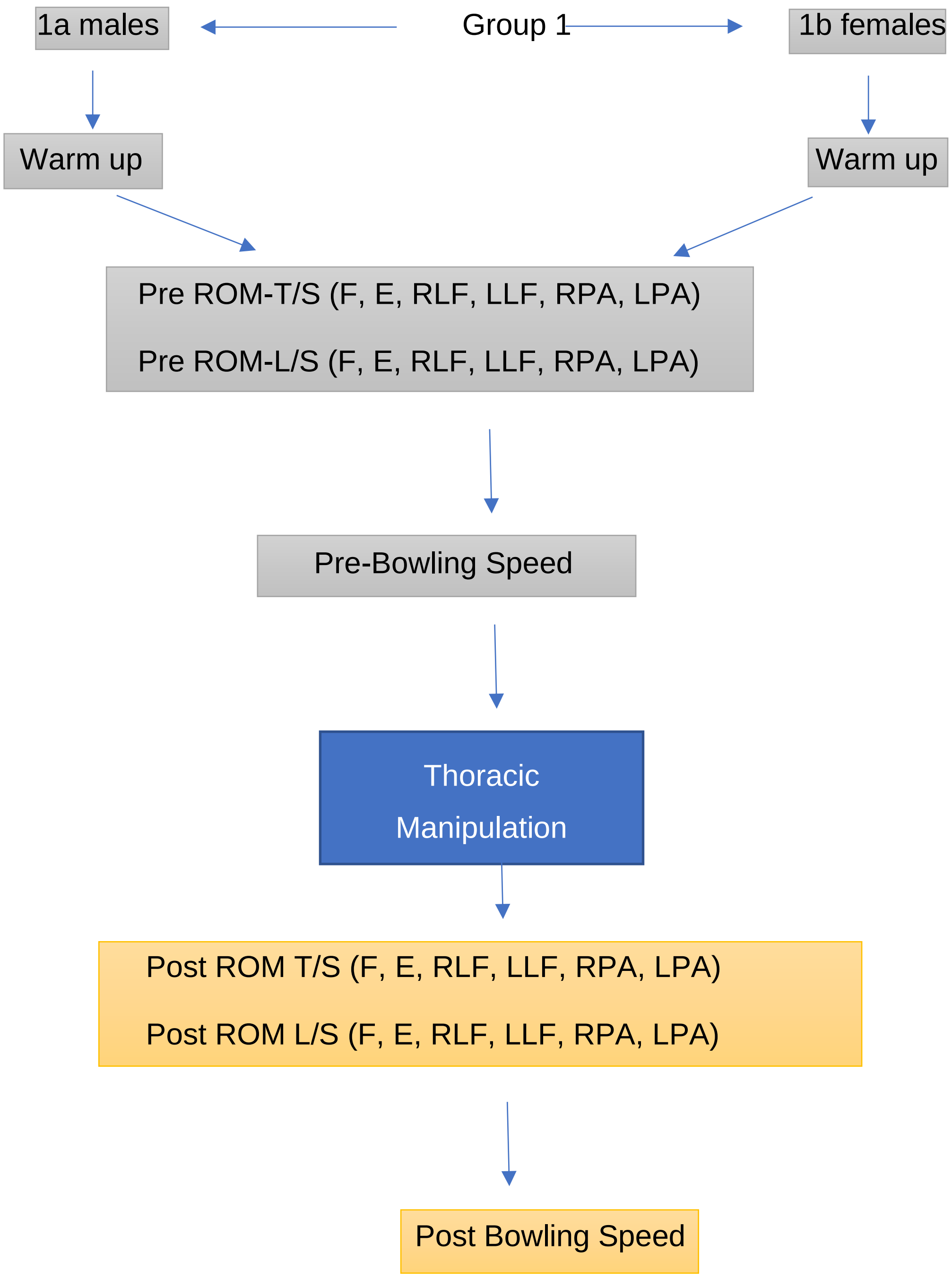
The inclinometer has shown a high level of validity when compared to the isokinetic dynamometer when assessing the knee joint in athletes. According to Bucke, Fawcett and Rushton (2017) the digital inclinometer showed valid measures of thoracic spine rotation in the heel seated position. The digital inclinometer had showed strong criterion validity when it was compared to the standard reference group. The above authors found that the digital inclinometer was useful in identifying thoracic spine restriction in asymptomatic individuals. The digital inclinometer could assist in evaluating the effect of therapeutic interventions on thoracic mobility and this would lead to improved athletic performance (Bucke, Fawcett, Rushton 2017).

Therefore, due to this, health and sports professionals can use the tool to monitor proprioceptive deterioration in athletes. There is only a slight margin for error with the use of the digital inclinometer and this is entirely due to the examiner’s ability to accurately locate the bony anatomical landmarks.

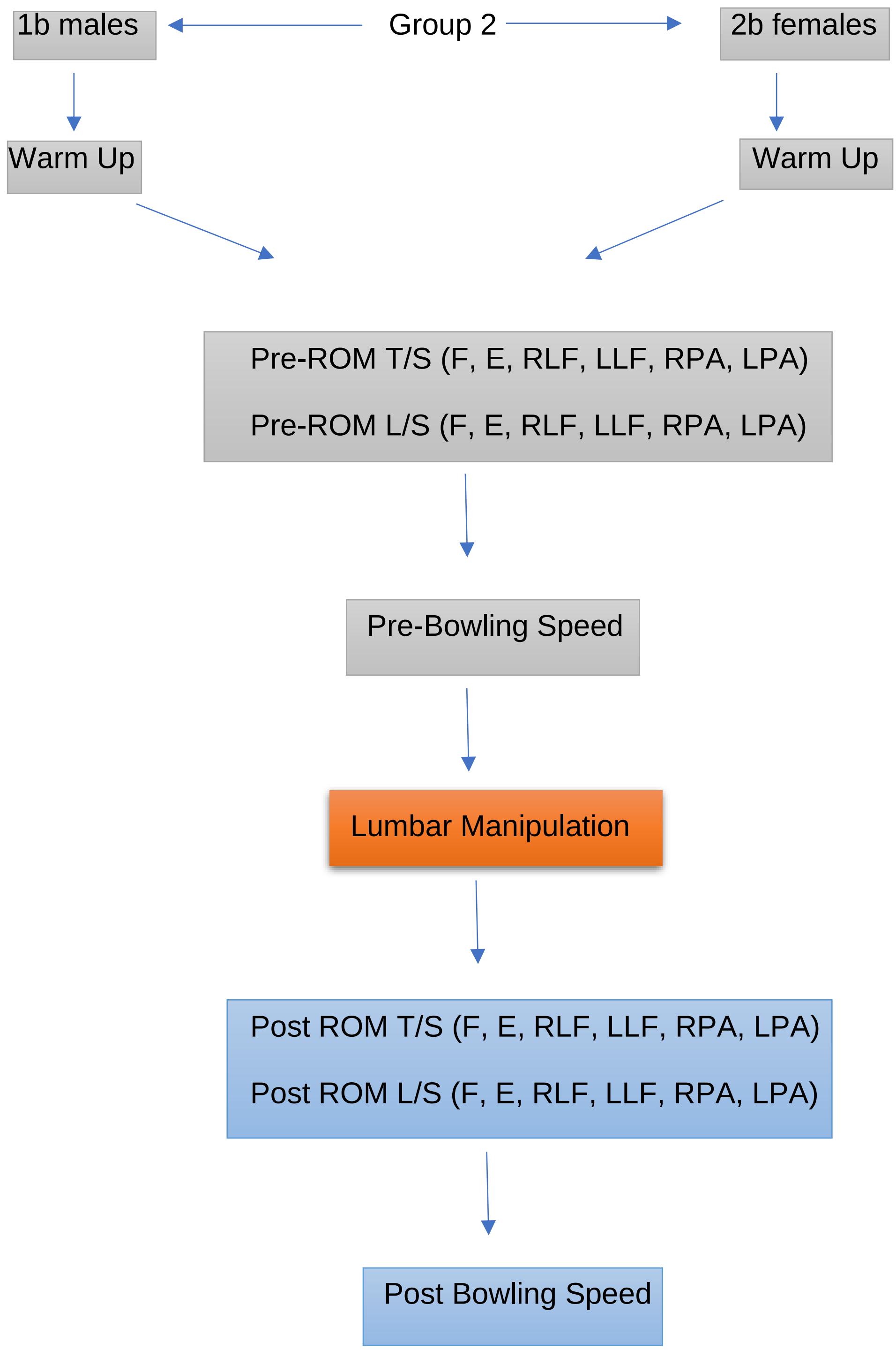
3.10.1.2 SpeedTrac

This machine uses the Doppler signalling process to measure small projectile speeds. When the ball is bowled, the radar monitor will display its speed, either in km/h or mph (kilometres per hour or miles per hour). The SpeedTrac machine was purchased and calibrated by the researcher.

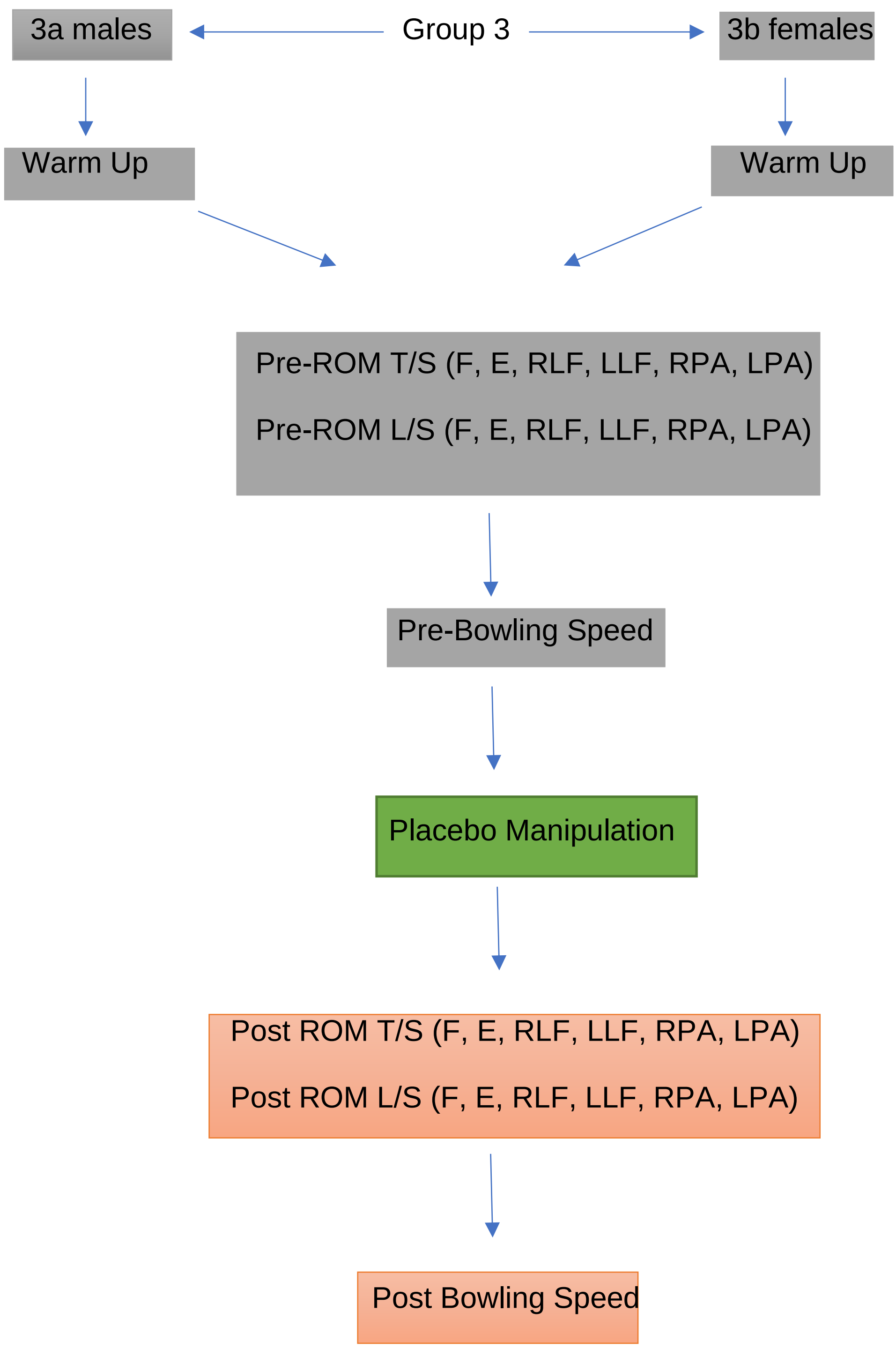
1. **Flow Diagram for Group 1 (thoracic manipulation)**



2. **Flow Diagram for Group 2 (Lumbar Manipulation)**



3. Flow Diagram for Group 3 (Placebo Manipulation)



3.11 PARTICIPANTS PERCEPTION OF BOWLING SPEED

Participants in all three groups had to answer the following question after the intervention: “Did you feel your bowling speed increased, decreased or remained the same after the intervention?”

3.12 ETHICAL CONSIDERATION IN THIS STUDY

- Participants were given a letter of information (**Appendix B**), which was read and understood before signing acceptance of the terms (**Appendix C).**
- Informed consent from (**Appendix C**) was read and signed.
- Ethical clearance was obtained from the Institutional Research Ethics Committee (IREC).
- Only participants who met the full inclusive criteria were selected for the study.
- Procedures were done in an enclosed arena for privacy and to ensure that there were no contraindications to spinal manipulation
- Some degree of deception was used in Group 3. Participants were informed that they were receiving a therapeutic intervention; however, sham manipulation was used.
- A qualified Chiropractor was present on site to supervise the entire procedure to ensure that there were no problems and that no unethical or improper behaviour was displayed.
- The principles of autonomy, non-maleficence, justice, and beneficence were followed.

3.13 DATA ANALYSIS

The data were analysed and then placed in an Excel spreadsheet. An updated SPSS version 25 was used to analyse the data. A p value of < 0.05 was of significance. Intra-group analysis used T tests to compare changes from pre-intervention and post-interventions. Variables were assessed for any variations from normality using the standard error method. Inter-group analysis used ANOVA testing to compare the mean change and percentage change in the intervention groups. The Fisher Comparison test was used to assess the association between participant perception in bowling speed change and mean bowling speed change (Singh 2017).

CHAPTER FOUR: STATEMENT OF FINDINGS AND RESULTS OF THE DATA

4.1 INTRODUCTION

This chapter contains the collected data results as per the methodology outlined in chapter three. This chapter presents the demographic data of the participants (age, height, weight), the results and discusses the subjective (participants' perception of change in bowling speed post intervention) and objective (thoracic and lumbar range of motion pre and post intervention) findings obtained from the study. The data collected were analysed using statistical software package SPSS version 25.0. The results present the descriptive statistics in the form of figures, cross tabulations and other illustrations for the quantitative data that were collected. Inferential techniques include the use of correlations and Mann Whitney test values, which were interpreted using *p*-values.

4.2 THE SAMPLE SIZE AND PARTICIPANTS

Table 4.1 Illustrates the randomization of the participants, (males and females) for each type of intervention. The sample comprised of participants as per the distribution below:

Table 4.1: Randomization of the participants for each type of intervention type

		Gender		Total
		Male	Female	
Type	Intervention 1 - thoracic spine manipulation	10	10	20
	Intervention 2 - lumbar spine manipulation	10	10	20
	Intervention 3 - placebo spine manipulation	10	10	20
Total		30	30	60

4.3 RESULTS

4.3.1 Physical Characteristics

Tables 4.2.1 to **4.2.6** show the number, minimum, maximum, mean, and standard deviation of the physical characteristics of participants, according to their groups and gender, which include age, weight (body mass) and height of the indoor cricket bowlers who participated in this study.

Table 4.2.1: Descriptive Statistics of Group 1a: Males

	Minimum	Median	Maximum	Range	Mean	Std deviation
Age (years)	19,00	22,0000	35,00	16,00	23,9000	5,13052
Height (m)	1.60	1,7600	1,81	0,21	1,7400	0,06515
Weight (kg)	62,00	85,5000	114,00	52,00	85,2000	13,38158

Table 4.2.2: Descriptive Statistics of Group 1b: Females

	Minimum	Median	Maximum	Range	Mean	Std deviation
Age (years)	18,00	24,5000	28,00	10,00	23,9000	3,54181
Height (m)	1,52	1,6600	1,71	0,19	1,6450	0,06223
Weight (kg)	48,80	61,1500	89,00	40,20	62,6100	12,11028

Table 4.2.3: Descriptive Statistics of Group 2a: Males

	Minimum	Median	Maximum	Range	Mean	Std deviation
Age (years)	22,00	25,5000	33,00	11,00	26,9000	4,22821
Height (m)	1,62	1,7700	1,88	0,26	1,7540	0,07961
Weight (kg)	64,00	81,5000	92,00	28,00	80,4000	8,89694

Table 4.2.4: Descriptive Statistics of Group 2b: Females

	Minimum	Median	Maximum	Range	Mean	Std deviation
Age (years)	19,00	21,0000	29,00	10,00	22,1000	3,38132
Height (m)	1,55	1,6000	1,65	0,10	1,5960	0,03239
Weight (kg)	51,00	59,0000	72,00	21,00	60,3000	6,95701

Table 4.2.5: Descriptive Statistics of Group 3a: Males

	Minimum	Median	Maximum	Range	Mean	Std deviation
Age (years)	21,00	26,5000	33,00	12,00	26,5000	3,83695
Height (m)	1,67	1,7800	1,88	0,21	1,7830	0,06701
Weight (kg)	68,00	79,5000	122,00	54,00	82,1000	15,23483

Table 4.2.6: Descriptive Statistics of Group 3b: Females

	Minimum	Median	Maximum	Range	Mean	Std deviation
Age (years)	18,00	24,5000	29,00	11,00	24,1000	3,95671
Height (m)	1,53	1,6550	1,71	0,18	1,6320	0,06391
Weight (kg)	52,00	67,0000	78,00	26,00	66,0000	9,34523

A total of 30 male and 30 female participants were included in the study, with each group consisting of 10 participants. The age of the male participants ranged from 19 to 35 years, and female participants ranged from 18 to 29 years. The height of the male participants ranged from 1,60 to 1,88 meters and female participants ranged from 1.52 to 1.71 meters.

The weight (mass) of the male participants ranged from 62 to 122 kg and female participants ranged from 48 to 89 kg. An UNIANOVA analysis was conducted to assess if there were any statistically significant differences in means between age, height, and weight groups. There was no statistical significance (*p*-value) found between the three variables (age, height, weight) in both male and female participants as shown in the table below. Upon physical examination, motion palpation, and thoracic spine and lumbar spine regional assessments of the participants, female participants presented with more relaxed erector spinae muscles compared to males.

Table 4.3: Comparison of *p*-value between participants

	Male *p*-value	Female *p*-value
Age (years)	0,142	0,469
Height (m)	0,495	0,098
Weight (kg)	0,455	0,385

4.3.2 Section Analysis

The section that follows analyses the scoring patterns of the participants per variable. The results are first presented using summarised means for the variables. Results are then further analysed according to the importance of the statements.

4.3.3 Normality Tests

The One-Sample Kolmogorov-Smirnov Test was used to test whether data were normally distributed. Most variables had *p*-values < 0.05, implying that the distributions were not normal. This meant using non-parametric analysis for the data.

4.3.4 Means Comparisons Between Male and Female Participants

Various scenarios for comparing the mean values were done as per the headings below. The tables, figures and data presented in this section report the findings of the study pre intervention and post intervention.

The table below compares males to females for each variable. There is no difference in the age between males and females (*p*-value = 0.064). However, there are significant differences between weight, height and range of motion as indicated in bold and highlighted in yellow.

Table 4.4: Comparison of male and female participants for each variable

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Age	325.000	790.000	-1.854	0.064
Height	64.500	529.500	-5.706	**0.000**
Weight	83.000	548.000	-5.430	**0.000**
Pre BS	183.500	648.500	-3.940	**0.000**
Pre flexion T/S Rom	406.500	871.500	-0.649	0.516
Pre extension T/S Rom	412.500	877.500	-0.562	0.574
Pre RLF T/S Rom	427.500	892.500	-0.335	0.738
Pre LLF T/S Rom	432.000	897.000	-0.268	0.789
Pre RPA T/S Rom	317.000	782.000	-1.983	**0.047**
Pre LPA T/S Rom	384.500	849.500	-0.979	0.327
Pre flexion L/S Rom	105.500	570.500	-5.102	**0.000**
Pre extension L/S Rom	373.000	838.000	-1.155	0.248
Pre RLF L/S Rom	244.000	709.000	-3.076	**0.002**
Pre LLF L/S Rom	312.000	777.000	-2.057	**0.040**
Pre RPA L/S Rom	111.500	576.500	-5.069	**0.000**
Pre LPA L/S Rom	75.000	540.000	-5.600	**0.000**
Post BS	187.000	652.000	-3.889	**0.000**
Post flexion T/S Rom	393.000	858.000	-0.848	0.396
Post extension T/S Rom	373.000	838.000	-1.146	0.252
Post RLF T/S Rom	450.000	915.000	0.000	1.000
Post LLF T/S Rom	446.000	911.000	-0.060	0.953
Post RPA T/S Rom	358.000	823.000	-1.370	0.171
Post LPA T/S Rom	363.500	828.500	-1.292	0.196
Post flexion L/S Rom	93.500	558.500	-5.277	**0.000**
Post extension L/S Rom	327.000	792.000	-1.838	0.066
Post RLF L/S Rom	276.500	741.500	-2.622	**0.009**
Post LLF L/S Rom	311.500	776.500	-2.066	**0.039**
Post RPA L/S Rom	115.500	580.500	-4.987	**0.000**
Post LPA L/S Rom	86.500	551.500	-5.421	**0.000**

4.3.5 Mean Comparisons of Thoracic and Lumbar ROM Between Male and Female Participants

Tables 4.5 to 4.10 shows the changes (pre and post) in thoracic spine range of motion post thoracic spine, lumbar spine and placebo spinal manipulation in both male and female participants.

Table 4.5: Changes in flexion of the T/S (pre and post intervention) in both male and female participants

		Pre flexion T/S Rom	Post flexion T/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	29.40	32.70	0,005
	Intervention 2 - lumbar spine manipulation	26.30	27.10	0,230
	Intervention 3 - placebo manipulation	27.80	27.50	0,417
Female	Intervention 1 - thoracic spine manipulation	28.40	31.40	0,005
	Intervention 2 - lumbar spine manipulation	27.10	28.20	0,159
	Intervention 3 - placebo manipulation	27.90	27.50	0,102

Table 4.5 above shows the relationship between thoracic spine flexion and the effect that the three interventions (thoracic, lumbar and placebo manipulation) had on both males and females. There were statistical significant increases in FF post thoracic manipulation (intervention 1) in male and female participants.

Table 4.6: Changes in means in extension of the T/Spine (pre and post intervention) in both male and female participants

		Pre extension T/S Rom	Post extension T/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	20,20	22,20	0,005
	Intervention 2 - lumbar spine manipulation	22,90	22,50	0,203
	Intervention 3 - placebo manipulation	22,70	22,00	0,223
Female	Intervention 1 - thoracic spine manipulation	22,80	24,50	0,004
	Intervention 2 - lumbar spine manipulation	21,30	23,10	0,008
	Intervention 3 - placebo manipulation	21,50	21,60	0,564

Table 4.6 shows the effect of thoacic, lumbar and placebo manipulation on extension of the thoracic spine in both male and female participants. Significant changes were visible post thoracic manipulation in males, while

female participants showed changes post thoracic and lumbar manipulation.

Table 4.7: Changes in means in right lateral flexion of the T/S (pre and post intervention) in both male and female participants

		Pre right lateral flexion T/S Rom	Post right lateral flexion T/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	23,50	26,90	0,005
	Intervention 2 - lumbar spine manipulation	26,40	28,80	0,008
	Intervention 3 - placebo manipulation	24,70	24,00	0,096
Female	Intervention 1 - thoracic spine manipulation	24,00	26,10	0,004
	Intervention 2 - lumbar spine manipulation	24,70	26,70	0,006
	Intervention 3 - placebo manipulation	26,30	26,10	0,317

Table 4.7 above depicts the effect of thoracic, lumbar and placebo manipulation on right lateral flexion of the T/Spine in both male and female participants. There were significant increases in RLF post thoracic and lumbar manipulation of both male and female participants.

Table 4.8: Changes in means in left Lateral flexion of the T/Spine (pre and post intervention) in both male and female participants

		Pre left lateral flexion T/S Rom	Post left lateral flexion T/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	23,10	25,40	0,031
	Intervention 2 - lumbar spine manipulation	25,60	29,70	0,007
	Intervention 3 - placebo manipulation	24,30	24,50	0,914
Female	Intervention 1 - thoracic spine manipulation	23,30	25,90	0,005
	Intervention 2 - lumbar spine manipulation	24,80	26,80	0,005
	Intervention 3 - placebo manipulation	26,20	25,90	0,083

Table 4.8 above depicts the changes in left lateral flexion of the T/Spine post T/S, L/S and placebo manipulation. Significant increases in LLF were shown post thoracic and lumbar manipulation.

Table 4.9: Changes in means in right rotation of the T/Spine (pre and post intervention) in both male and female participants

		Pre right rotation T/S Rom	Post right rotation T/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	19,70	22,60	0,007
	Intervention 2 - lumbar spine manipulation	18,90	20,20	0,070
	Intervention 3 - placebo manipulation	21,00	21,30	0,705
Female	Intervention 1 - thoracic spine manipulation	21,20	23,40	0,004
	Intervention 2 - lumbar spine manipulation	20,30	22,20	0,004
	Intervention 3 - placebo manipulation	21,20	21,10	0,317

Table 4.9 above outlines the changes of right rotational ROM in both male and female participants. The evidence above shows significant increases post thoracic manipulation in males and post thoracic and lumbar manipulation in females. As visible in the above table there were slight changes post placebo manipulation, however, it is not significant. This could be due to inaccuracy of the digital inclinometer or participants excessive movement.

Table 4.10: Changes in means in left rotation of the T/Spine (pre and post intervention) in both male and female participants

		Pre left rotation T/S Rom	Post left rotation T/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	20,40	23,00	0,006
	Intervention 2 - lumbar spine manipulation	19,30	19,90	0,196
	Intervention 3 - placebo manipulation	21,50	21,30	0,480
Female	Intervention 1 - thoracic spine manipulation	23,00	21,30	0,004
	Intervention 2 - lumbar spine manipulation	20,20	22,20	0,005
	Intervention 3 - placebo manipulation	21,40	21,50	0,317

Table 4.10 above depicts the changes in left rotational movement of the thoracic spine post T/S, L/S and placebo manipulation in both male and female participants. The evidence presented in the above table shows LPA increased significantly post thoracic manipulation in males and post thoracic and lumbar manipulation in females.

Tables 4.11 to **4.17** show the changes in means in lumbar spine range of motion pre and post thoracic, lumbar and placebo spinal manipulation in both male and female participants.

Table 4.11: Changes in means in flexion of the L/Spine (pre and post intervention) in both male and female participants

		Pre flexion L/S Rom	Post flexion L/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	64,50	66,10	0,004
	Intervention 2 - lumbar spine manipulation	60,30	64,00	0,005
	Intervention 3 - placebo manipulation	63,80	63,20	0,058
Female	Intervention 1 - thoracic spine manipulation	50,20	51,40	0,028
	Intervention 2 - lumbar spine manipulation	51,70	52,70	0,008
	Intervention 3 - placebo manipulation	52,30	52,30	1,000

Table 4.11 above show the changes in lumbar forward flexion post T/S, L/S, and placebo manipulation in male and female participants. Significant increases (p-value less than 0.05) in forward flexion were shown post thoracic and lumbar manipulation in both genders (highlighted in yellow).

Table 4.12: Changes in means in extension of the L/Spine (pre and post intervention) in both male and female participants

		Pre extension L/S Rom	Post extension L/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	18,40	18,60	0,726
	Intervention 2 - lumbar spine manipulation	20,10	20,90	0,084
	Intervention 3 - placebo manipulation	18,80	18,40	0,157
Female	Intervention 1 - thoracic spine manipulation	19,90	20,90	0,119
	Intervention 2 - lumbar spine manipulation	19,70	20,40	0,053
	Intervention 3 - placebo manipulation	20,30	20,40	0,317

Table 4.12 above depicts the changes in extension of the lumbar spine post T/S, L/S and placebo manipulation. There were no statistical significant findings. The p-values were more than 0.05.

Table 4.13: Changes in means in right lateral flexion of the L/Spine pre and post intervention in male and female participants

		Pre right lateral flexion L/S Rom	Post right lateral flexion L/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	17,40	18,50	0,075
	Intervention 2 - lumbar spine manipulation	20,50	21,70	0,383
	Intervention 3 - placebo manipulation	17,60	17,80	0,414
Female	Intervention 1 - thoracic spine manipulation	22,20	23,60	0,006
	Intervention 2 - lumbar spine manipulation	19,70	21,20	0,005
	Intervention 3 - placebo manipulation	20,90	21,00	0,317

Table 4.13 depicts the changes in RLF in the lumbar spine post T/S, L/S and placebo manipulation. RLF significantly increased post thoracic and lumbar manipulation in female participants only, p-value <0.05 as deicted in yellow highlight.

The table below show the means for RLF of the lumbar spine between male and female participants. It is evident that female participants have a higher RLF than male.

Table 4.14: Mean and standard deviations values for male and female participants pre right lateral flexion of the L/S Rom

	Male	Female
Mean	18.50	20.93
95% Confidence Interval for Mean: Lower Bound	17.22	20.01
Upper Bound	19.78	21.85
5% Trimmed Mean	18.48	20.81
Median	19.00	21.00
Variance	11.78	6.06
Std. Deviation	3.43	2.46
Minimum	11.00	17.00
Maximum	26.00	27.00
Range	15.00	10.00
Interquartile Range	5.00	3.00
Skewness	0.13	0.96
Kurtosis	0.53	1.37

It is clearly evident in **Table 4.14** that females have a higher left lateral flexion then males. According to Sullivan *et al*. (1994) females have greater joint mobility and flexibility then males in both the coronal and sagittal planes.

Table 4.15: Changes in left lateral flexion of the L/Spine pre and post intervention in male and female participants

		Pre left lateral flexion L/S Rom	Post left lateral flexion L/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	17,40	17,80	0,434
	Intervention 2 - lumbar spine manipulation	20,50	22,00	0,080
	Intervention 3 - placebo manipulation	18,30	17,90	0,257
Female	Intervention 1 - thoracic spine manipulation	22,40	23,50	0,009
	Intervention 2 - lumbar spine manipulation	19,40	20,80	0,004
	Intervention 3 - placebo manipulation	20,40	20,40	1,000

Table 4.15 depicts the changes in LLF of L/S post T/S, L/S and placebo manipulation. Siginicant differences were shown in female participants only (p-values, 0,009 and 0,004).

Table 4.16: Changes in means in right rotation of L/Spine pre and post intervention in male and female participants

		Pre right rotation L/S Rom	Post right rotation L/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	11,40	12,30	0,014
	Intervention 2 - lumbar spine manipulation	10,50	12,80	0,008
	Intervention 3 - placebo manipulation	10,00	10,10	0,655
Female	Intervention 1 - thoracic spine manipulation	6,90	8,80	0,006
	Intervention 2 - lumbar spine manipulation	7,40	8,80	0,004
	Intervention 3 - placebo manipulation	7,50	7,50	1,000

Table 4.16 depict the changes in right rotation of the L/S post T/S, LS and placebo manipulation. Statistically significant increases were shown (indicated in highlight) post thoracic and lumbar manipulation in male and female participants.

Table 4.17: Changes in means in left rotation of the L/Spine pre and post intervention in male and female participants

		Pre left rotation L/S Rom	Post left rotation L/S Rom	*p*-values
Male	Intervention 1 - thoracic spine manipulation	11,00	12,20	0,016
	Intervention 2 - lumbar spine manipulation	10,70	13,10	0,005
	Intervention 3 - placebo manipulation	10,00	10,10	0,564
Female	Intervention 1 - thoracic spine manipulation	7,40	8,90	0,007
	Intervention 2 - lumbar spine manipulation	7,10	8,40	0,009
	Intervention 3 - placebo manipulation	6,70	6,70	1,000

Table 4.17 depict the changes in left rotation of the L/Spine post T/S, L/S and placebo manipulation. LPA significantly increased post thoracic and lumbar manipulation in both genders (indicated in highlight).

4.3.6 Mean Comparisons of Bowling Speed pre and post intervention

The bowling speed means (pre and post) intervention and *p* values in both male and female participants are shown in the following table.

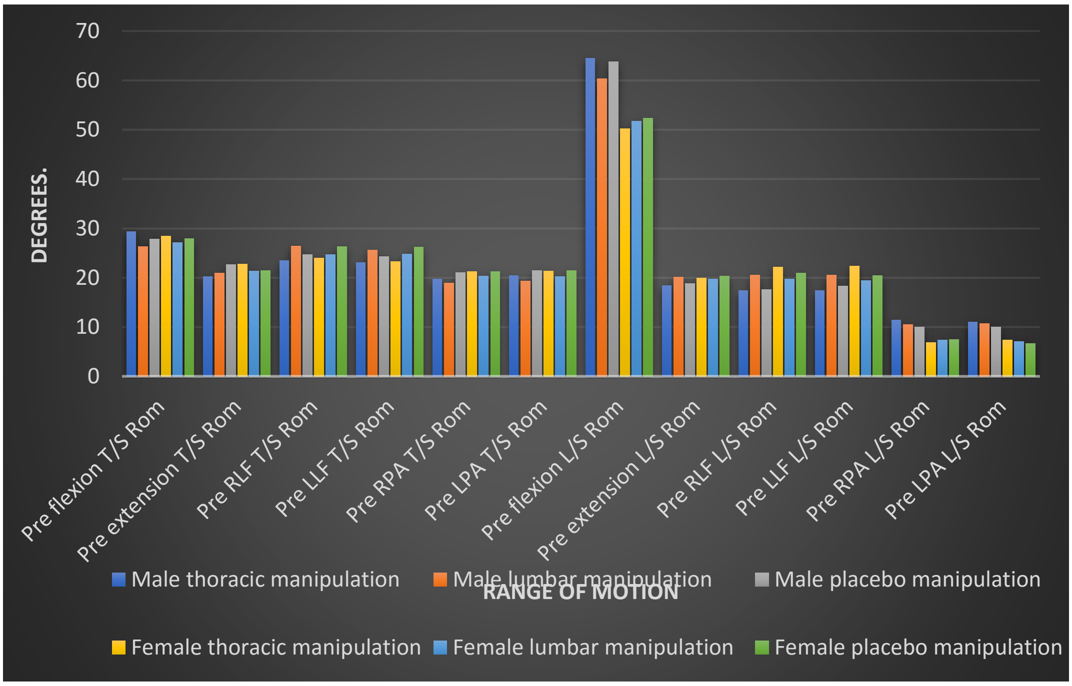
Table 4.18: Bowling speed means (pre and post) intervention and *p* values in both male and female participants

		Pre BS	Post BS	*p*-values
Male	Intervention 1 - thoracic spine manipulation	90.39	94.74	0.005
	Intervention 2 - lumbar spine manipulation	85.42	85.54	0.539
	Intervention 3 - placebo manipulation	86.06	86.19	0.339
Female	Intervention 1 - thoracic spine manipulation	75.95	79.47	0.005
	Intervention 2 - lumbar spine manipulation	69.44	69.38	1.000
	Intervention 3 - placebo manipulation	78.88	78.72	0.157

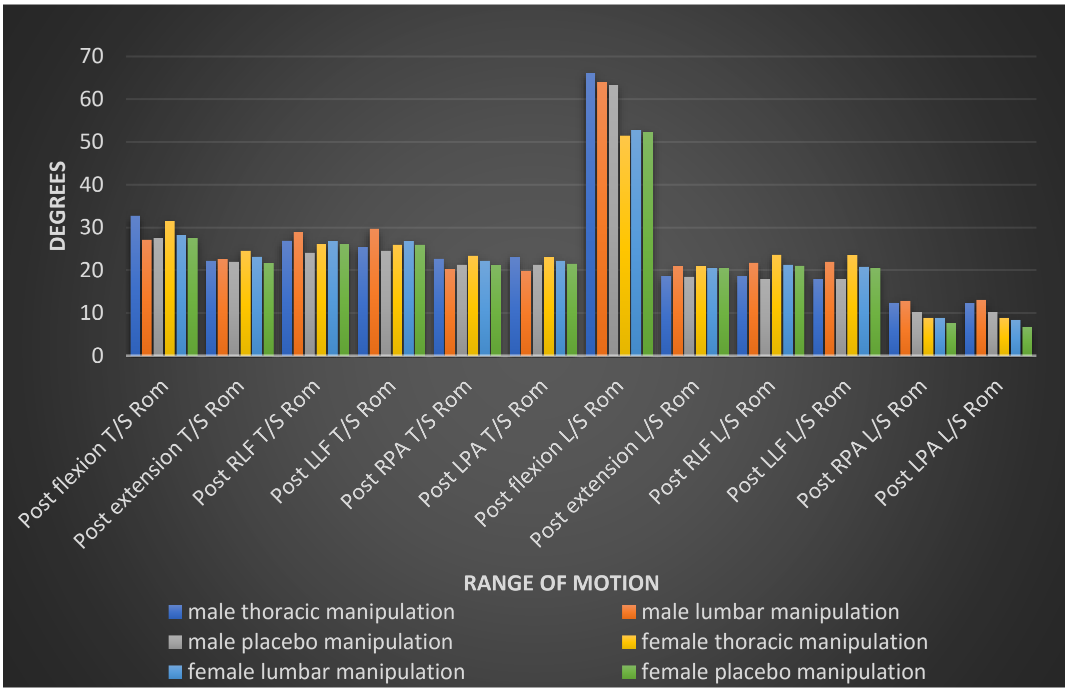
In **Table 4.18** the following patterns are observed. The bowling speeds for males is higher than that for females. In both genders, there are differences in the pre and post speeds (indicated in yellow highlight). The significance of the differences are tested and shown in the table above.

4.3.7 Mean comparisons between Range of Motion and Bowling Speed

The following graphs show the effect of thoracic, lumbar, and placebo manipulation on range of motion (thoracic and lumbar spine) and bowling speed in male and female indoor cricket bowlers.

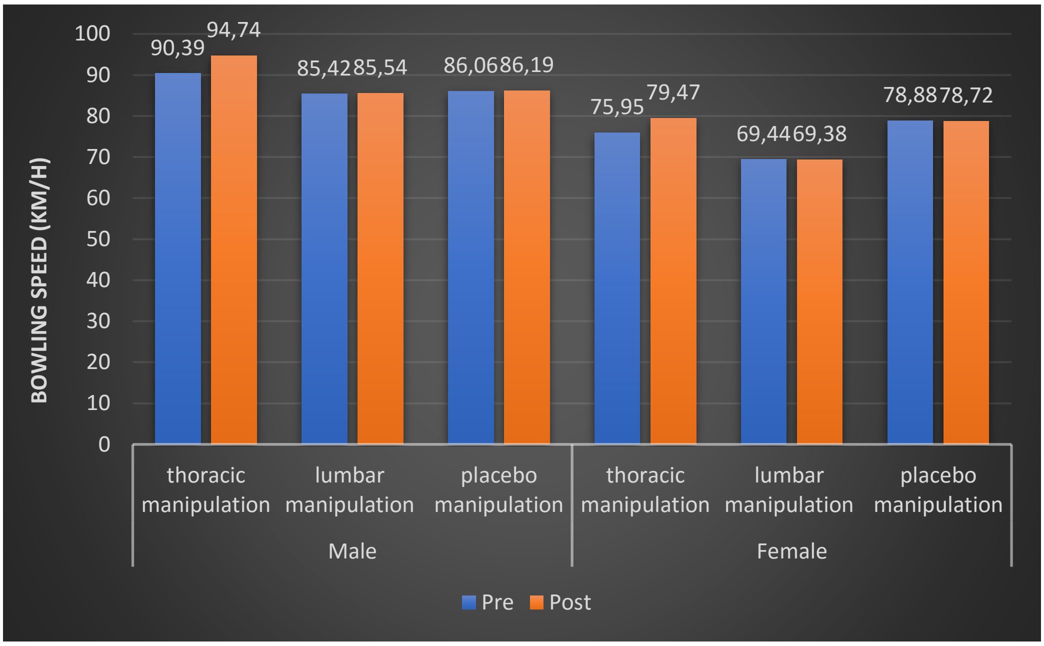


Graph 4.1: Mean values of range of motion in the thoracic and lumbar spine pre manipulation (thoracic, lumbar and placebo)



Graph 4.2: Changes in ROM post thoracic, lumbar, and placebo manipulation in male and female indoor cricket bowlers

The above **Graphs 4.1** and **4.2** depicts the changes in thoracic and lumbar range of motion pre manipulation and post manipulation (thoracic, lumbar, and placebo). As illustrated in the above graph thoracic and lumbar SMT showed significant increases in both thoracic and lumbar ROM. These findings correlate with the conclusions of many authors that SMT positively enhances ROM.



Graph 4.3: Change in bowling speed in male and female indoor cricket bowlers pre and post manipulation (thoracic, lumbar and placebo)

As presented in the above **Graph 4.3,** it is evident that thoracic manipulation had significantly increased bowling speed in male and female indoor cricket bowlers as compared to lumbar and placebo manipulation.

4.3.8 Intra-group analysis

Intra-group analysis was carried out on each variable using non-parametric tests to compare the change from pre and post between the groups.

4.3.8.1 Intra-group analysis for Group 1a and 1b

The intra-group analysis for Groups 1a and Group 1b is shown in **Tables 4.19** to **4.24** In **Table 4.19** and **Table 4.22**, wherein the median, mean, standard deviation, standard deviation error, and 95% coincidence level are shown.

In **Table 4.20** and **Table 4.23** the correlations between pre and post readings are depicted, and **Table 4.21** and **Table 4.24** show the Wilcoxon table that describes the significant values.

Table 4.19: Paired sample statistics of Group 1a (Males) – Thoracic Manipulation

	N	Median	Mean	Std deviation
Pre bowling speed	10	94,0800	90,3880	13,95684
Post bowling speed	10	98,5600	94,7360	14,16890
Pre T/S FF	10	27,00	29,40	5,21110
Post T/S FF	10	31,00	32,70	6,34298
Pre T/S Ext	10	20,50	20,20	3,19026
Post T/S Ext	10	22,00	22,20	2,93636
Pre T/S RLF	10	22,00	23,50	4,35252
Post T/S RLF	10	25,50	26,90	5,15213
Pre T/S LLF	10	23,50	23,10	3,69534
Post T/S LLF	10	25,00	25,40	5,05964
Pre T/S RPA	10	20,00	19,70	1,41814
Post T/S RPA	10	22,50	22,60	1,42984
Pre T/S LPA	10	20,50	20,40	2,75681
Post T/S LPA	10	23,00	23,00	2,26078
Pre L/S FF	10	66,00	64,50	10,28753
Post L/S FF	10	68,00	66,10	10,01610
Pre L/S Ext	10	19,00	18,40	2,71621
Post L/S Ext	10	19,50	18,60	3,16390
Pre L/S RLF	10	17,50	17,40	2,27058
Post L/S RLF	10	18,00	18,50	3,27448
Pre L/S LLF	10	16,50	17,40	2,71621
Post L/S LLF	10	17,00	17,80	3,52136
Pre L/S RPA	10	11,00	11,40	2,22111
Post L/S RPA	10	12,00	12,30	2,35938
Pre L/S LPA	10	11,00	11,00	1,94365
Post L/S LPA	10	12,00	12,20	1,98886

The above table depicts the changes in bowling speed and ROM (thoracic and lumbar) post thoracic spine manipulation. It is evident that thoracic SMT significantly increased bowling speed and thoracic and lumbar ROM in male participants.

Table 4.20: Paired samples correlations of Group 1a (Males) – Thoracic Manipulation

	N	Correlation	Sig
Pre bowling speed vs post bolwing speed	10	.998**	0,000
Pre T/S FF vs Post T/S FF	10	.992**	0,000
Pre T/S Ext vs Post T/S Ext	10	.968**	0,000
Pre T/S RLF vs Post T/S RLF	10	0,589	0,073
Pre T/S LLF vs Post T/S LLF	10	.877**	0,001
Pre RPA vs Post T/S RPA	10	-0,121	0,740
Pre T/S LPA vs Post T/S LPA	10	.642*	0,045
Pre L/S FF vs Post L/S FF	10	.998**	0,000
Pre L/S Ext vs Post L/S Ext	10	.898**	0,000
Pre L/S RLF vs Post L/S RLF	10	0,553	0,097
Pre L/S LLF vs Post L/S LLF	10	0,033	0,929
Pre L/S RPA vs Post L/S RPA	10	.950**	0,000
Pre L/S LPA vs Post L/S LPA	10	.862**	0,001

Table 4.20 shows the correlations between thoracic SMT, bowling speed and thoracic and lumbar ROM in male participants. There is a significant relationship visible (yellow hightlight), with a p value of <0.05.

Table 4.21: Males – Group 1a- Thoracic Manipulation - Wilcoxon

	N	Z	Sig
Post flexion T/S Rom - Pre flexion T/S Rom	10	-1.633[c]	0,102
Post extension T/S Rom - Pre extension T/S Rom	10	-.577[d]	0,564
Post RLF T/S Rom - Pre RLF-T/S Rom	10	-1.000[c]	0,317
Post LLF T/S Rom - Pre LLF-T/S Rom	10	-1.732[c]	0,083
Post RPA T/S Rom - Pre RPA-T/S Rom	10	-1.000[c]	0,317
Post LPA T/S Rom - Pre LPA-T/S Rom	10	-1.000[d]	0,317
Post flexion L/S Rom - Pre flexion L/S Rom	10	.000[e]	1,000
Post extension L/S Rom - Pre extension L/S Rom	10	-1.000[d]	0,317
Post RLF L/S Rom - Pre RLF-L/S Rom	10	-1.000[d]	0,317
Post LLF L/S Rom - Pre LLF-L/S Rom	10	.000[e]	1,000
Post RPA L/S Rom - Pre RPA-L/S Rom	10	.000[e]	1,000
Post LPA L/S Rom - Pre LPA-L/S Rom	10	.000[e]	1,000

Table 4.21: shows the non-parametric tests used to explain the Hypothesis of the study. The table shows that there were no statistical significant changes post thoracic SMT.

Table 4.22: Paired sample statistics of Group 1a (Females) – Thoracic Manipulation

	N	Median	Mean	Std deviation
Pre bowling speed	10	78,3000	75,9480	11,04367
Post bowling speed	10	81,8400	79,4680	11,06053
Pre T/S FF	10	28,50	28,40	1,50555
Post T/S FF	10	31,50	31,40	1,42984
Pre T/S Ext	10	23,00	22,80	2,44040
Post T/S Ext	10	25,00	24,50	2,71825
Pre T/S RLF	10	24,00	24,00	1,94365
Post T/S RLF	10	24,00	24,00	1,94365
Pre T/S LLF	10	23,00	23,30	2,00278
Post T/S LLF	10	25,90	26,00	1,91195
Pre T/S RPA	10	22,00	21,20	1,39841
Post T/S RPA	10	23,50	23,40	1,57762
Pre T/S LPA	10	21,50	21,30	1,88856
Post T/S LPA	10	23,50	23,00	2,05480
Pre L/S FF	10	51,00	50,20	4,73286
Post L/S FF	10	53,00	51,40	5,01553
Pre L/S Ext	10	20,00	19,90	1,66333
Post L/S Ext	10	21,50	20,90	1,96921
Pre L/S RLF	10	21,00	22,00	3,29309
Post L/S RLF	10	22,00	23,60	3,02581
Pre L/S LLF	10	22,00	22,40	2,91357
Post L/S LLF	10	22,50	23,50	2,67706
Pre L/S RPA	10	7,00	6,90	1,59513
Post L/S RPA	10	8,50	8,80	1,39841
Pre L/S LPA	10	7,00	7,40	1,34990
Post L/S LPA	10	8,50	8,90	1,28668

Table 4.22 depicts the results post thoracic SMT in female participants. The table shows that post SMT, bowling speed, and thoracic and lumbar ROM significantly increased.

Table 4.23: Paired samples of correlation in Group 1b (Females) – Thoracic manipulation

	N	Correlation	Sig
Pre bowling speed vs post bolwing speed	10	.997**	0,000
Pre T/S FF vs Post T/S FF	10	.846**	0,002
Pre T/S Ext vs Post T/S Ext	10	.971**	0,000
Pre T/S RLF vs Post T/S RLF	10	.958**	0,000
Pre T/S LLF vs Post T/S LLF	10	.850**	0,002
Pre RPA vs Post T/S RPA	10	0,514	0,192
Pre T/S LPA vs Post T/S LPA	10	.973**	0,000
Pre L/S FF vs Post L/S FF	10	.965**	0,000
Pre L/S Ext vs Post L/S Ext	10	0,539	0,108
Pre L/S RLF vs Post L/S RLF	10	.979**	0,000
Pre L/S LLF vs Post L/S LLF	10	.969**	0,000
Pre L/S RPA vs Post L/S RPA	10	.837**	0,003
Pre L/S LPA vs Post L/S LPA	10	.793**	0,006

Table 4.23 shows the correlations between thoracic SMT, bowling speed and thoracic and lumbar ROM in female participants. There are several statistical significant increases (p value <0.05), depicted in yellow highlight.

Table 4.24: Females – Thoracic Manipulation – Group 1b - Wilcoxon

	N	Z	Sig
Post flexion T/S Rom - Pre flexion T/S Rom	10	-2.836[c]	0,005
Post extension T/S Rom - Pre extension T/S Rom	10	-2.859[c]	0,004
Post RLF T/S Rom - Pre RLF-T/S Rom	10	-2.913[c]	0,004
Post LLF T/S Rom - Pre LLF-T/S Rom	10	-2.827[c]	0,005
Post RPA T/S Rom - Pre RPA-T/S Rom	10	-2.848[c]	0,004
Post LPA T/S Rom - Pre LPA-T/S Rom	10	-2.919[c]	0,004
Post flexion L/S Rom - Pre flexion L/S Rom	10	-2.203[c]	0,028
Post extension L/S Rom - Pre extension L/S Rom	10	-1.558[c]	0,119
Post RLF L/S Rom - Pre RLF-L/S Rom	10	-2.739[c]	0,006
Post LLF L/S Rom - Pre LLF-L/S Rom	10	-2.598[c]	0,009
Post RPA L/S Rom - Pre RPA-L/S Rom	10	-2.754[c]	0,006
Post LPA L/S Rom - Pre LPA-L/S Rom	10	-2.714[c]	0,007

Table 4.24: shows statistically significant changes (yellow highlight) post thoracic SMT in female participants (p value <0.05), with exception to lumbar spine extension.

4.3.8.2 Intra-group analysis for Group 2a and 2b

The intra-group analysis for Group 2a and Group 2b are shown in **Tables 4.25** to **4.30.** In **Table 4.25** and **Table 4.28,** the median, mean, and standard deviation are shown. In **Table 4.26** and **4.29** the correlation between pre readings and post readings are depicted, and **Table 4.27** and **Table 4.30** show the Wilcoxon table that describes the significance among the bowling speed, ranges of motion, and interventions.

Table 4.25: Paired samples of statistics in Group 2a (Males) – Lumbar Manipulation

	N	Median	Mean	Std deviation
Pre B/S	10	89,6800	85,4240	12,38883
Post B/S	10	88,8800	85,5360	12,15654
Pre T/S FF	10	26,50	26,30	2,49666
Post T/S FF	10	27,00	27,10	3,66515
Pre T/S Ext	10	22,00	20,90	2,76687
Post T/S Ext	10	22,00	22,50	4,67262
Pre T/S RLF	10	27,00	26,40	6,16802
Post T/S RLF	10	30,50	28,80	5,41192
Pre T/S LLF	10	25,50	25,60	5,29570
Post T/S LLF	10	31,00	29,70	5,09762
Pre T/S RPA	10	18,00	18,90	3,10734
Post T/S RPA	10	19,00	20,20	3,99444
Pre T/S LPA	10	20,00	19,30	3,16403
Post T/S LPA	10	21,00	19,00	3,51030
Pre L/S FF	10	61,00	60,30	7,42443
Post L/S FF	10	62,00	62,50	3,66515
Pre L/S Ext	10	20,50	20,10	3,44642
Post L/S Ext	10	22,00	22,50	4,67262
Pre L/S RLF	10	19,00	20,50	3,24037
Post L/S RLF	10	30,50	28,80	5,41192
Pre L/S LLF	10	20,50	20,50	2,54951
Post L/S LLF	10	21,50	22,00	4,02768
Pre L/S RPA	10	10,50	10,50	2,27303
Post L/S RPA	10	13,00	12,80	1,47573
Pre L/S LPA	10	10,50	10,70	2,62679
Post L/S LPA	10	12,50	13,10	2,02485

Table 4.25: lumbar and thoracic ROM signifcantly increased post lumbar SMT in male participants.

Table 4.26: Paired Samples of Correlations in Group 2a (Males) - Lumbar Manipulation

	N	Correlation	Sig
Pre bowling speed vs post bolwing speed	10	.999**	1,000
Pre T/S FF vs Post T/S FF	10	.822**	0,004
Pre T/S Ext vs Post T/S Ext	10	0,529	0,116
Pre T/S RLF vs Post T/S RLF	10	.968**	0,000
Pre T/S LLF vs Post T/S LLF	10	.639*	0,047
Pre RPA vs Post T/S RPA	10	.888**	0,001
Pre T/S LPA vs Post T/S LPA	10	.893**	0,000
Pre L/S FF vs Post L/S FF	10	.920**	0,000
Pre L/S Ext vs Post L/S Ext	10	.980**	0,000
Pre L/S RLF vs Post L/S RLF	10	0,538	0,109
Pre L/S LLF vs Post L/S LLF	10	.822**	0,003
Pre L/S RPA vs Post L/S RPA	10	.696*	0,026
Pre L/S LPA vs Post L/S LPA	10	.925**	0,000

In **Table 4.26**, there are significant relationships (yellow highlight) between lumbar SMT, and thoracic and lumbar ROM (p value <0.05) in male participants.

Table 4.27: Males – Lumbar manipulation – Group 2a - Wilcoxon

	N	Z	Sig
Post flexion T/S Rom - Pre flexion T/S Rom	10	-1.201[c]	0,230
Post extension T/S Rom - Pre extension T/S Rom	10	-1.273	0,203
Post RLF T/S Rom - Pre RLF-T/S Rom	10	-2.666[c]	0,008
Post LLF T/S Rom - Pre LLF-T/S Rom	10	-2.684[c]	0,007
Post RPA T/S Rom - Pre RPA-T/S Rom	10	-1.811[c]	0,070
Post LPA T/S Rom - Pre LPA-T/S Rom	10	-1.294[c]	0,196
Post flexion L/S Rom - Pre flexion L/S Rom	10	-2.820[c]	0,005
Post extension L/S Rom - Pre extension L/S Rom	10	-1.725[c]	0,084
Post RLF L/S Rom - Pre RLF-L/S Rom	10	-.872[c]	0,383
Post LLF L/S Rom - Pre LLF-L/S Rom	10	-1.750[c]	0,080
Post RPA L/S Rom - Pre RPA-L/S Rom	10	-2.671[c]	0,008
Post LPA L/S Rom - Pre LPA-L/S Rom	10	-2.827[c]	0,005

Table 4.27 explains the null hypothesis partially, that intervention group 2 will have no effect on bowling speed and/ or ROM (thoracic and lumbar).

Table 4.28: Paired samples of statistics in Group 2b (Females) – Lumbar Manipulation

	N	Median	Mean	Std deviation
Pre bowling speed	10	65,8400	69,4400	6,78571
Post bowling speed	10	66,5600	69,3760	6,61299
Pre T/S FF	10	26,5000	27,1000	2,23358
Post T/S FF	10	28,00	28,20	4,26354
Pre T/S Ext	10	21,00	21,30	1,33749
Post T/S Ext	10	23,00	23,10	1,66333
Pre T/S RLF	10	24,50	24,70	1,56702
Post T/S RLF	10	27,00	26,70	1,49442
Pre T/S LLF	10	25,00	24,80	1,93218
Post T/S LLF	10	27,00	26,80	1,54919
Pre T/S RPA	10	21,50	20,30	3,43350
Post T/S RPA	10	23,00	22,20	3,22490
Pre T/S LPA	10	21,00	20,20	2,09762
Post T/S LPA	10	22,00	22,20	2,44040
Pre L/S FF	10	51,50	51,70	4,83161
Post L/S FF	10	52,50	52,70	5,25040
Pre L/S Ext	10	19,50	19,70	1,49443
Post L/S Ext	10	20,50	20,40	1,83787
Pre L/S RLF	10	20,00	19,70	1,94651
Post L/S RLF	10	22,00	21,20	1,68655
Pre L/S LLF	10	20,00	19,40	2,17051
Post L/S LLF	10	21,50	20,80	1,98886
Pre L/S RPA	10	7,00	7,40	1,17379
Post L/S RPA	10	9,00	8,00	1,13529
Pre L/S LPA	10	7,00	7,10	0,99443
Post L/S LPA	10	8,00	8,40	0,51640

Table 4.28 shows that post lumbar SMT, lumbar and thoracic ROM increased, however bowling speed did not show a significant change.

Table 4.29: Paired samples of correlations in Group 2b (Females) – Lumbar Manipulation

	N	Correlation	Sig
Pre bowling speed vs post bolwing speed	10	.988**	0,000
Pre T/S FF vs Post T/S FF	10	0,558	0,094
Pre T/S Ext vs Post T/S Ext	10	.784**	0,007
Pre T/S RLF vs Post T/S RLF	10	.811**	0,004
Pre T/S LLF vs Post T/S LLF	10	0,221	0,539
Pre RPA vs Post T/S RPA	10	.897**	0,000
Pre T/S LPA vs Post T/S LPA	10	0,062	0,864
Pre L/S FF vs Post L/S FF	10	-0,112	0,758
Pre L/S Ext vs Post L/S Ext	10	-0,304	0,393
Pre L/S RLF vs Post L/S RLF	10	.856**	0,002
Pre L/S LLF vs Post L/S LLF	10	0,038	0,917
Pre L/S RPA vs Post L/S RPA	10	0,512	0,131
Pre L/S LPA vs Post L/S LPA	10	-0,018	0,961

Table 4.29 shows that there is a significant correlation (yellow highlight) between lumbar SMT and thoracic and lumbar ROM (p value <0.05). The correlation between lumbar SMT and bowling speed exists, as there was no change, thus correlating with the studies of Sood (2008) and Robson (2018).

Table 4.30: Female – Lumbar Manipulation – Group 2b – Wilcoxon Table

	N	Z	Sig
Post flexion T/S Rom - Pre flexion T/S Rom	10	-1.409[c]	0,159
Post extension T/S Rom - Pre extension T/S Rom	10	-2.640[c]	0,008
Post RLF T/S Rom - Pre RLF-T/S Rom	10	-2.724[c]	0,006
Post LLF T/S Rom - Pre LLF-T/S Rom	10	-2.836[c]	0,005
Post RPA T/S Rom - Pre RPA-T/S Rom	10	-2.913[c]	0,004
Post LPA T/S Rom - Pre LPA-T/S Rom	10	-2.836[c]	0,005
Post flexion L/S Rom - Pre flexion L/S Rom	10	-2.640[c]	0,008
Post extension L/S Rom - Pre extension L/S Rom	10	-1.933[c]	0,053
Post RLF L/S Rom - Pre RLF-L/S Rom	10	-2.879[c]	0,004
Post LLF L/S Rom - Pre LLF-L/S Rom	10	-2.889[c]	0,004
Post RPA L/S Rom - Pre RPA-L/S Rom	10	-2.889[c]	0,004
Post LPA L/S Rom - Pre LPA-L/S Rom	10	-2.598[c]	0,009

Table 4.30 depicts the statistically significant changes (yellow highlight) post lumbar SMT in thoracic and lumbar ROM in female participants.

4.3.8.3 Intra-group analysis for Group 3a and Group 3b

The intra-group analysis for Group 3a and Group 3b are shown in **Tables 4.31 to 4.36.** In **Table 4.31** and **Table 4.34,** the median, mean, and standard deviation are depicted. **Table 4.32** and **Table 4.35** depict the correlations between the pre, and post readings and **Table 4.33** and **Table 4.36** show the Wilcoxon table that describes the significance among the bowling speed, ranges of motion and interventions.

Table 4.31: Paired Samples of Statistics in Group 3a (Males) – Placebo Manipulation

	N	Median	Mean	Std deviation
Pre B/S	10	86,9600	86,0640	9,72407
Post B/S	10	87,2000	86,1920	9,47325
Pre T/S FF	10	27,50	27,80	1,54919
Post T/S FF	10	28,00	27,50	1,43372
Pre T/S Ext	10	23,00	22,70	2,62679
Post T/S Ext	10	21,50	22,00	3,33333
Pre T/S RLF	10	25,50	24,70	4,76212
Post T/S RLF	10	24,50	24,00	5,35413
Pre T/S LLF	10	24,50	24,30	4,76212
Post T/S LLF	10	25,00	24,50	5,79751
Pre T/S RPA	10	21,00	21,00	2,66667
Post T/S RPA	10	21,50	21,30	2,26323
Pre T/S LPA	10	22,00	21,50	3,37474
Post T/S LPA	10	22,00	21,30	3,02030
Pre L/S FF	10	64,00	63,80	6,64664
Post L/S FF	10	63,00	63,20	6,17882
Pre L/S Ext	10	19,00	18,80	2,65832
Post L/S Ext	10	19,00	18,40	2,98887
Pre L/S RLF	10	19,00	17,60	3,94968
Post L/S RLF	10	18,50	17,80	3,93841
Pre L/S LLF	10	19,50	18,30	3,68330
Post L/S LLF	10	19,50	17,90	3,92853
Pre L/S RPA	10	9,50	10,00	2,78887
Post L/S RPA	10	10,00	10,10	2,46982
Pre L/S LPA	10	10,00	10,00	2,30940
Post L/S LPA	10	9,50	10,10	2,51440

In **Table 4.31**, the placebo SMT had no statistical significant change on bowling speed, and thoracic and lumbar ROM.

Table 4.32: Paired samples of Correlations in Group 3a (Males) – Placebo Manipulation

	N	Correlation	Sig
Pre bowling speed vs post bolwing speed	10	.999**	0,000
Pre T/S FF vs Post T/S FF	10	.650*	0.042
Pre T/S Ext vs Post T/S Ext	10	.863**	0,001
Pre T/S RLF vs Post T/S RLF	10	.972**	0,000
Pre T/S LLF vs Post T/S LLF	10	.972**	0,000
Pre RPA vs Post T/S RPA	10	.847**	0,002
Pre T/S LPA vs Post T/S LPA	10	.965**	0,000
Pre L/S FF vs Post L/S FF	10	.994**	0,000
Pre L/S Ext vs Post L/S Ext	10	.962**	0,000
Pre L/S RLF vs Post L/S RLF	10	.980**	0,000
Pre L/S LLF vs Post L/S LLF	10	.962**	0,000
Pre L/S RPA vs Post L/S RPA	10	.968**	0,000
Pre L/S LPA vs Post L/S LPA	10	.976**	0,000

Table 4.31 depicts the correlation between the placebo SMT, bowling speed and ROM. There were no significant changes.

Table 4.33: Males – Group 3a – Placebo manipulation - Wilcoxon

	N	Z	Sig
Post flexion T/S Rom - Pre flexion T/S Rom	10	-.812[c]	0,417
Post extension T/S Rom - Pre extension T/S Rom	10	-1.219[c]	0,223
Post RLF T/S Rom - Pre RLF T/S Rom	10	-1.667[c]	0,096
Post LLF T/S Rom - Pre LLF T/S Rom	10	-.108[d]	0,914
Post RPA T/S Rom - Pre RPA T/S Rom	10	-.378[d]	0,705
Post LPA T/S Rom - Pre LPA T/S Rom	10	-.707[c]	0,480
Post flexion L/S Rom - Pre flexion L/S Rom	10	-1.897[c]	0,058
Post extension L/S Rom - Pre extension L/S Rom	10	-1.414[c]	0,157
Post RLF L/S Rom - Pre RLF L/S Rom	10	-.816[d]	0,414
Post LLF L/S Rom - Pre LLF L/S Rom	10	-.816[d]	0,257
Post RPA L/S Rom - Pre RPA L/S Rom	10	-.447[d]	0,655
Post LPA L/S Rom - Pre LPA L/S Rom	10	-.577[d]	0,564

Table 4.33: post placebo SMT there were no chnages in ROM, thus agreeing with the Null Hypothesis (4), that there would be no statistically significant relationship between measured change in bowling speeds immediately post intervention and the participants' perception of change in bowling speed.

Table 4.34: Paired Samples of Statistics of Group 3b (Females) – Placebo Manipulation

	N	Median	Mean	Std deviation
Pre bowling speed	10	80,7200	78,8800	10,91680
Post bowling speed	10	80,2400	78,7240	10,72474
Pre T/S FF	10	28,00	27,90	2,72641
Post T/S FF	10	27,50	27,50	2,54951
Pre T/S Ext	10	21,50	21,50	2,27303
Post T/S Ext	10	21,50	21,60	2,36643
Pre T/S RLF	10	26,50	26,30	1,88856
Post T/S RLF	10	25,50	26,10	1,91195
Pre T/S LLF	10	26,00	26,20	1,61933
Post T/S LLF	10	26,00	25,90	1,52388
Pre T/S RPA	10	22,00	21,20	2,85968
Post T/S RPA	10	21,50	21,00	2,84605
Pre T/S LPA	10	22,00	21,40	2,83627
Post T/S LPA	10	22,00	21,50	2,87711
Pre L/S FF	10	51,50	52,30	3,94546
Post L/S FF	10	51,50	52,30	3,94546
Pre L/S Ext	10	20,50	20,30	1,63639
Post L/S Ext	10	20,50	20,40	1,57762
Pre L/S RLF	10	21,00	20,90	1,19722
Post L/S RLF	10	21,00	21,00	1,33333
Pre L/S LLF	10	20,50	20,40	1,77639
Post L/S LLF	10	20,50	20,40	1,77639
Pre L/S RPA	10	7,00	7,50	1,64992
Post L/S RPA	10	7,00	7,50	1,64992
Pre L/S LPA	10	6,50	6,70	1,33749
Post L/S LPA	10	6,50	6,70	1,33749

Table 4.34 shows that post placebo SMT there were no significant increases in bowling speed and ROM (thoracic an lumbar) in the female participants.

Table 4.35: Paired Samples of Correlations in Group 3b (Females) – Placebo Manipulation

	N	Correlation	Sig
Pre bowling speed vs post bolwing speed	10	1.000**	0,000
Pre T/S FF vs Post T/S FF	10	.967**	0,000
Pre T/S Ext vs Post T/S Ext	10	.971**	0,000
Pre T/S RLF vs Post T/S RLF	10	.945**	0,000
Pre T/S LLF vs Post T/S LLF	10	.955**	0,000
Pre RPA vs Post T/S RPA	10	.994**	0,000
Pre T/S LPA vs Post T/S LPA	10	.994**	0,000
Pre L/S FF vs Post L/S FF	10	1.000**	0,000
Pre L/S Ext vs Post L/S Ext	10	.981**	0,000
Pre L/S RLF vs Post L/S RLF	10	.974**	0,000
Pre L/S LLF vs Post L/S LLF	10	1.000**	0,000
Pre L/S RPA vs Post L/S RPA	10	1.000**	0,000
Pre L/S LPA vs Post L/S LPA	10	1.000**	0,000

Table 4.35 shows the correlations between placebo SMT, bowling speed and thoracic and lumbar ROM. A relationship exists as there were no changes and was significant (control group), correlating with the Null Hypothesis 4.

Table 4.36: Female – Placebo Manipulation – Group 3b – Wilcoxon

	N	Z	Sig
Post flexion T/S Rom - Pre flexion T/S Rom	10	-1.633[c]	0,102
Post extension T/S Rom - Pre extension T/S Rom	10	-.577[d]	0,564
Post RLF T/S Rom - Pre RLF-T/S Rom	10	-1.000[c]	0,317
Post LLF T/S Rom - Pre LLF-T/S Rom	10	-1.732[c]	0,083
Post RPA T/S Rom - Pre RPA-T/S Rom	10	-1.000[c]	0,317
Post LPA T/S Rom - Pre LPA-T/S Rom	10	-1.000[d]	0,317
Post flexion L/S Rom - Pre flexion L/S Rom	10	.000[e]	1,000
Post extension L/S Rom - Pre extension L/S Rom	10	-1.000[d]	0,317
Post RLF L/S Rom - Pre RLF-L/S Rom	10	-1.000[d]	0,317
Post LLF L/S Rom - Pre LLF-L/S Rom	10	.000[e]	1,000
Post RPA L/S Rom - Pre RPA-L/S Rom	10	.000[e]	1,000
Post LPA L/S Rom - Pre LPA-L/S Rom	10	.000[e]	1,000

Table 4.36 explains the null hypothesis (2). There would be no statistically significant increases in range of motion for any of the three groups there is no statistical difference post placebo SMT in thoracic and lumbar SMT.

4.3.9 Intergroup Analysis

Inter-group analysis determines the comparison of mean change between the three intervention groups using the UNIANOVA comparison tests. Pearson's correlation analysis was used to examine the strength of any linear relationships between changes in outcome variables.

An UNIANOVA test was conducted on the variables to determine whether there is a difference in mean values across the three groups.

Table 4.37 tests for comparison of mean change between bowling speed in the three intervention groups. Beta (B) represents the linear regression, Significant (Sig) are the values which is set to 0.05 and Partial Eta Squared explains the effect size (0.02 – small effect, 0.06 – medium effect and 0.12 a large effect) as highlighted in yellow.

Table 4.37: UNIANOVA test for comparison of mean change between bowling speed intervention groups

Parameter	B	Std. Error	T	Sig.	Partial Eta Squared
Intercept	-0,036	0,175	-0,204	0,839	0,001
Flexion T/S Rom	-0,013	0,059	-0,228	0,820	0,001
Extension T/S Rom	-0,057	0,082	-0,692	0,492	0,011
RLF T/S Rom	0,069	0,077	0,893	0,377	0,017
LLF T/S Rom	-0,008	0,060	-0,139	0,890	0,000
RPA T/S Rom	0,018	0,126	0,142	0,888	0,000
LPA T/S Rom	0,016	0,144	0,109	0,914	0,000
Flexion L/S Rom	0,069	0,078	0,889	0,379	0,017
Extension L/S Rom	-0,207	0,100	-2,077	0,044	0,087
RLF L/S Rom	0,099	0,105	0,937	0,354	0,019
LLF L/S Rom	-0,038	0,081	-0,472	0,639	0,005
RPA L/S Rom	-0,186	0,132	-1,408	0,166	0,042
LPA L/S Rom	0,123	0,123	1,000	0,323	0,022
Thoracic SMT	3,896	0,564	6,912	0,000	0,515
Lumbar SMT	0,026	0,554	0,047	0,963	0,000
Placebo SMT	0[a]				

a. This parameter is set to zero because it is redundant.

The above **Table 4.37** depicts the changes that occur in bowling speed between the three intervention groups. Placebo SMT is the reference group. The table shows that thoracic SMT (green highlight) significantly enhanced bowling speed.

4.3.10 The Association Between Change in Bowling Speed pre and post intervention and Participants' Perception of Change in Bowling Speed

A cross tabulation for the groups reported that there were statistically significant changes calculated using the Fisher test between male *p*-value (0,032) and female *p*-value (0,0072) and between changes in bowling speed pre intervention and post intervention and participants' perception of change in bowling speed.

Table 4.38: Participants' perception of change in bowling speed by gender (males) and groups of intervention

Type		Increased	Decreased	No change
Group A	Percentage%	70%	10%	20%
Group B	Percentage %	40%	40%	20%
Group C	Percentage %	10%	20%	70%
Total	Count	40%	23,33%	36,66%

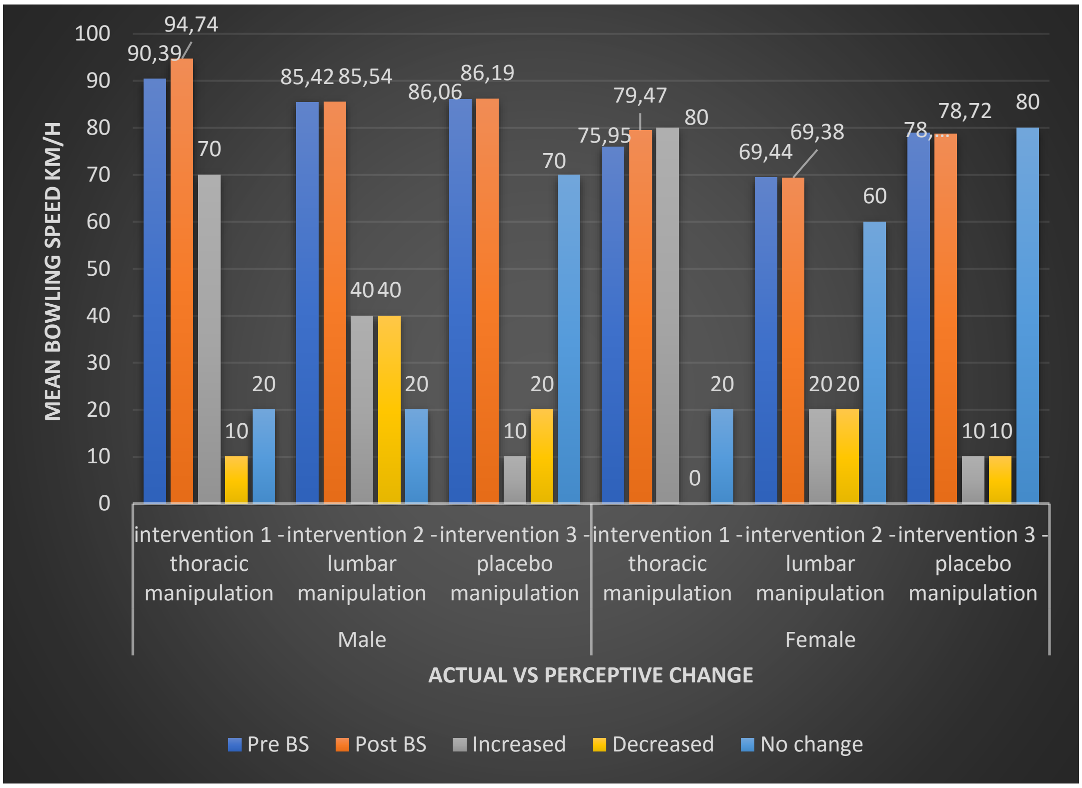
The above **Table 4.38**. depicts the participants' perception on change in bowling speed post intervention. Of the participants, 40% of the participants perceived an increase in their bowling speed, 23.33% a decrease and 36.66% said there was no change.

Table 4.39: Participants perception of change in bowling speed by gender (females) and group of intervention (Female)

Type		Increased	Decreased	No Change
Group A	Count	8	0	2
	Percentage%	80%	0%	20%
Group B	Count	2	2	6
	Percentage %	20%	20%	60%
Group C	Count	1	1	8
	Percentage %	10%	10%	80%
Total	Count	11	3	16
	Percentage %	36,66%	10%	53,33%

The **Table 4.39** above shows the participants' perception of change in bowling speed post intervention. Of the participants, 36.66% perceived an increase in bowling speed, 10% a decrease and 53.33% said there was no change.

Graph 4.4 shows the correlation between actual change in bowling speed vs participants perception of change in bowling speed.



Graph 4.4: Correlation between actual change in bowling speed vs participants perception of change in bowling speed

The above figure shows the association between the change in actual bowling speed versus the participants' perception of change. It is evident that the bowling speed increased post thoracic manipulation significantly, as compared to lumbar manipulation and placebo manipulation. Participants in intervention Group 1a and b also perceived that their bowling speed increased. Thus, correlating that actual change in bowling speed and the participants' perception had a directly proportional relationship.

CHAPTER FIVE: DISCUSSION OF FINDINGS

5.1 INTRODUCTION

This chapter will discuss the results of chapter four, the statistical analysis and the relevant literature delving into possible reasons or explanations for the results.

5.2 FLOW OF PARTICIPANTS

The KZN cricket league has a population size of 200 players (males and females), 60 of which could bowl and were therefore suitable for this study.

The 60 participants were divided into one of three groups randomly, with each group consisting of 10 participants. All participants completed the research process with no injuries or adverse reactions reported (offsite supervisors were present during the data collection).

- Group 1a – males – thoracic spine manipulation
- Group 1b – females – thoracic spine manipulation
- Group 2a – males – lumbar spine manipulation
- Group 2b – females – lumbar spine manipulation
- Group 3a – males – placebo manipulation
- Group 3b - females – placebo manipulation

5.3 PHYSICAL CHARACTERISTICS

The average (± SD) age of the participants in this study, as shown in **Table 4.2.1**, indicated that most cricket players are young adults (18-34) years as reported by Thomas (2017). Due to the mixed nature of cricket games (Munro and Christie 2018), both males and females participated in this study. All the participants who participated in this study were asymptomatic individuals, similar to the studies of Sood (2008); Deutshmann (2015) and Robson (2018).

There were no statistically significant differences within the three groups in terms of age, weight, and height, in both male and female participants, when looked at separately (**Tables 4.3)**. Due to the comparison between genders, there were statistically significant differences between the physical characteristics (weight and height). There is no statistical difference in age, as indicated in **Table 4.4**, between male and females, *p*-value (0,064).

However, the above-mentioned table show there were significant differences found in other variables as indicated in bold and highlighted in yellow in the tables. According to **Table 4.4** there were statistically significant relationships between height, weight, and bowling speed between male and female participants. This significant finding implies that male participants were taller and broader, thus bowling speed was higher in the males than females. This finding correlates with the literature reported by Felton *et al.* 2018, that due to female participants having a short torso, arm lengths and height, females would still produce a slower ball speed in comparison to males.

Chu *et al.* (2009); and Felton *et al.* (2018) postulated that males and females differ physically. Felton *et al*. (2018) stated that men were stronger, had broader shoulders and longer arm lengths, as compared to female participants, who generally had narrow shoulders, shorter arms, shorter legs, and less muscular mass. A further highlighted point by the above authors is that due to physical differences between males and females there were different results obtained in the studies. A study conducted by Felton et al. (2018) found that females significantly had a slower ball release speed as compared to males.

The body mass index (BMI) or muscle mass may differ in males and females, but the spine, which lies between the skull and the pelvis, is similar. According to the evidence found in this research, females propelled the ball at a slower velocity as compared to males (**Table 4.18**). Thus, correlating with the conclusions made by the above authors, that due to physical characteristics, males could propel the ball at a higher velocity than females.

As concluded by several authors (Hansen *et al,* 2009; Cui *et al* 2013) estrogen, beyond its function as a sex hormone, plays a vital role in development, maturation and aging of muscles, tendons, and bones. Estrogen directly affects the structure and functions of muscle, tendon, and ligament and improves muscle mass and strength. Unlike the improvement of function in bone and muscles, estrogen reduces stiffness within tendons and ligaments, and thus has a direct relationship with performance levels and injury rates. In competitive athletes, estrogen levels are usually higher than in non-competitve indivuals. Athletes would have a higher maximal muscle repair and low progesterone, thus ensuing there is a high rate of force development resulting in better performance and a reduction in musculoskeltal injuries.

Due to the similar means in the demographics and physical characteristics, data biasness was eliminated within the male and female groups (**Tables 4.2.1** to **4.2.6** and **Table 4.3)**. According to Van den Tillaar and Ettema (2004), this would prevent one of the three groups having a superior advantage in terms of mean characteristics, which can affect the performance analysis among the intervention groups. The participants' age, physical characteristics (height and weight) and experience level are all factors that can affect a bowler's bowling speed. Therefore, it is important that there is no significant difference within the groups for demographics, as discussed by Sood (2008) and Robson (2018).

5.4 RANGE OF MOTION (ROM) FINDINGS

5.4.1 Discussion of the Thoracic Spine and Lumbar Spine Range of Motion findings Pre and Post Intervention in Groups 1a and b.

The baseline mean values (±SD) indicated in **Tables 4.19** to **4.24**, post thoracic manipulation shows the variability in the measurements of the thoracic and lumbar spine range of motion. As postulated by Moore, Dalley and Agur (2010), the baseline measurements presented in **Table 2.1** and **Table 2.2** are within the normal ROM limits as seen in asymptomatic individuals.

The baseline mean values (±SD) presented in **Table 4.25** and **Table 4.30** (post lumbar manipulation) illustrate the variability in the measurements of Thoracic FF, Ext, Thoracic LLAT, Thoracic RLAT, Thoracic RPA, Thoracic LPA, Lumbar FF, Ext, Lumbar LLAT, Lumbar RLAT, Lumbar RPA, and Lumbar LPA ROM. The baseline thoracic spine and lumbar spine ROM (±SD) specified in these tables are within the standard ROM limits **(Table 2.1** and **Table 2.2)** for asymptomatic individuals, as described by Moore, Dalley and Agur (2010).

As presented in **Table 4.14**, females had a higher pre and post L/S RLF as compared to male participants. Sullivan *et al.* (1994) and Van Herp *et al.* (2000) postulated that females exhibited greater sagittal and coronal ROM and joint mobility, especially in lateral flexion, than male participants. According to Umezu *et al* (1998), women showed more resitance to fatigue then men and women have a higher muscle endurance then men.

The ROM findings in this study are similar to that of Sood (2008); Deutschmann (2015); Wiggett (2015); and Robson (2018), who similarly used the Saunders Digital Inclinometer in objective ROM measuring. This confirms the claim by Czaprowski *et al*. (2012) that the Saunders digital inclinometer is a measuring device that has intra-observer and inter-observer repeatability of measurements.

5.5 THE EFFECT OF SPINAL MANIPULATION ON THORACIC AND LUMBAR ROM

5.5.1 Thoracic Range of Motion (ROM)

The results reported in **Tables 4.5 – 4.10** and **Graph 4.1** and **Graph 4.2** proved that both thoracic and lumbar spinal manipulation enhanced trunk range of motion and joint mobility, as postulated by Saunders *et al.* (1998); Myburgh and Kruger (1999); Whittingham and Nilsson (2001), and Millan *et al.* (2012) in both male and female participants.

Forward flexion (FF) of the thoracic spine (T/S) increased significantly post thoracic spine manipulation in both male and female participants, as indicated in **Table 4.5** and **Graph 4.2**, with *p*-value in males (0,005) and with *p*-values in females (0,005). This, therefore, implies that the relationship is directly proportional and statistically significant. In the male participants' lumbar and placebo manipulation showed no statistical difference as both manipulations had no significant effect on FF of the thoracic spine, *p*-value (0,417 and 0,230). In the female participants, interventions 2 and 3 similarly showed no significant effect on thoracic spine FF, thus resulting in a statistically insignificant, *p*-values of (0,159 and 0,102).

According to **Table 4.6** and **Graph 4.2**, post thoracic spine manipulation there were statistically significant changes in extension of the thoracic spine in both male (*p*-value 0,005) and female (*p*-value 0,004) participants, and thus implying that thoracic spine manipulation has a positive effect on thoracic spine extension range of motion.

There was no statistical significant difference between lumbar and placebo manipulation on extension of the thoracic spine in male (*p*-values 0,203 and 0,223) participants. However, lumbar manipulation in the female participants (*p*-value 0,008) showed a significant change, thus implying that lumbar manipulation positively impacts thoracic extension ROM in females. Placebo manipulation was insignificant (*p*-value 0,564) in female participants.

Due to the attachment, insertion and actions of the erector spinae muscles, lumbar manipulation increased thoracic extension. This muscle runs vertically on either side of the spine. The superfical part attaches to the thoracic spine and ribs, while the deep part attaches to the lumbar spine. The thoracic and lumbar portions of the muscle are strong extensors of the vertebral column. The erector spinae muscles act bilaterally to extend the vertebral column and head.

According to Korr (1976), Pickar (2002) and Brigitte (2019) stated that spinal manipulation has several neurophysiological effects. SMT increases joint mobilty by producing a barrage of impulses in the muscle spindle afferents and smaller diameter afferents ultimately silencing the facilitated y loop.

Post manipulation the y loop motorneuron discharge is elevated in muscles of the vertebral segments. Therefore SMT stimulates muscle spindle afferents. This implies that SMT of the lumbar spine releases the adhesions, trapped meniscoids, and normalises the buckled segment, allowing increased mobility within the thoracoclumbar area.

Lumbar SMT, between the levels 2-3, was applied to all participants in this study. The erector spinae muscles attach and insert to lumbar and thoracic vertebrae bodies, and thus, the findings in this study correlate with the above-mentioned theories of the effect of the erector spinae muscles. .

The reflex control of spinal mobility is dependable on the sensorimotor mechanisms that are modulated by the mechanoreceptor afferents (Sanchez-Zuriaga, Adams and Dolan 2010). According to Sanchez-Zuriaga, Adams and Dolan (2010), the reflex action of the back muscles act to limit spinal flexion and therefore protect the underlying spine from injury. However repeated flexion allows bending moments on the spine to increase. The contributing factors could be related to muscle fatigue or soft tissue creep. The above authors found that the reflex muslce activation of the thoracic and lumbar erector spinae in response to a sudden perturbation was delayed due to creep (majority) and fatigue (lesser extent). Prolonged creep could alter the sensorimotor control mechanisms within the spine, thus affecting mobility. According to Umezu *et al.* (1998), women show more resitance to fatigue then men and women have a higher muscle endurance then men.

Concerning post thoracic spine and lumbar spine manipulation, a statistical significance is visible (**Table 4.7** and **Graph 4.2**) in thoracic RLF in male (*p*-values 0,005 and 0,008) and female (*p*-values 0,004 and 0,006) participants. Therefore, thoracic and lumbar spine manipulation positively affects right lateral flexion motion in the thoracic spine. Post placebo manipulation showed no statistical significance.

According to the changes that are visible in **Table 4.8** and **Graph 4.2,** both T/S and L/S manipulation resulted in statistically significant increases in LLF of the T/S in both male (*p*-values 0,031 and 0,007) and female (*p*-values

0,005 and 0,005) participants. Placebo manipulation (*p*-values 0,914 and 0,083) was statistically insignificant.

SMT of the lumbar spine enhanced RLF of the thoracic spine, and this occurred due to the action of the right lattissimus dorsi muscle. According to Moore, Dalley and Agur (2010), the lattissimus dorsi muscle is broad and runs between the trunk and the humerus via an extensive attachment. It attaches from the iliac crest, 5th lumbar vertebrae, 7th thoracic vertebrae, thoracolumbar fascia, inferior angle of the scapula and lower ribs. It inserts to the floor of the bicipital groove of the humerus. This muscle actively assists with lateral flexion of the trunk. However, in a standing upright position lateral flexion is aided by gravity and the lattissimus dorsi muscle.

Post thoracic spine manipulation (**Table 4.9** and **Graph 4.2**) showed males had a significant change in RPA rotation, (*p*-value (0,007). However, lumbar and placebo manipulation had no effect on RPA ROM, (*p*-value (0,070 and 0,705). Thoracic manipulation and lumbar manipulation significantly influenced right rotational ROM in female participants, with (*p*-values (0,004 and 0,004), thus implying that thoracic spine and lumbar spine manipulation positively influence rotation in the throacic region in female athletes. Placebo manipulation showed no statistical significance, with a *p* value of (0,317).

Thoracic and lumbar SMT was applied to selective levels in both male and female cricket bowlers, between levels 6-8 in the thoracic spine and levels 2-3 in the lumbar spine. As stated above, thoracic SMT enhanced RPA in males and females, but, however, lumbar SMT only enhanced RPA in females. As mentioned by Hansen et al 2009, estrogen plays a vital role in development, and maturation of muscular fibres. Estrogen enhances muscle mass, functioning of muscles, athletes performance levels, and reduces injury rates.

According to **Table 4.10** and **Graph 4.2**, there is a statistically significant change post thoracic spine manipulation in left rotation of the thoracic spine in male participants, (*p* value (0,006). However, there were no significant changes post lumbar and placebo manipulation, *p* values (0,196 and 0,480).

In female participants, there were statistically significant changes post thoracic and lumbar spine manipulation (*p* values 0,004 and 0,005), thus implying that both thoracic and lumbar spine manipulation positively influence left rotational ROM. There were no significant changes post placebo manipulation, (*p* value 0,317).

In the above thoracic spine findings, it is evident that lumbar SMT positively influences extension, RLF, LLF, RPA and LPA ROM in females only as compared to male participants. As concluded by Umeza *et al.* (1998), females were more resistant to muscle fatigue and had a higher muscle endurance than males. Movement was done with minimal muscle contraction that was required.

In summary, the thoracic spine has a close association with the glenohumeral joint due to the scapulothoracic joint and several muscular attachments between the shoulder and spine (Moore, Dalley and Agur 2015). This results in increased thoracic ROM post manipulation due to the eccentric muscle contraction on the ipisilateral side which was corrected by SMT. There were statistically significant changes in thoracic ROM post thoracic manipulation and lumbar manipulation. As reported by Engel, Dawe and Edwards (2017), the reason for these changes were due to the unbuckling of ligaments and the release of trapped meniscoids, the breaking of adhesions, and increased neurological input change in position of anatomical structures and thus, there was a return to normal ROM (Reed *et al*. 2017).

The glenohumeral joint is unable to release the ball on its own. Majority of the energy, force, speed, and motion required for bowling comes from the trunk. The shoulder and trunk work coherently in the bowling action. A subluxation has been reported to affect an individual’s performance. The spine is the most important structure in the body. It not only protects the spinal cord, but it aids in spinal mobility, innervates the skin, muscles, tendons, and ligaments. The spine serves as a funnel and link between the lower extremity and upper extremity. Movement within the extremities occur due to the neural input from the spine. If there is a subluxation in the shoulder, trunk, and pelvis in the throwing athlete, then this would result in a decline in performance. Thus Korr (1976), Pickar (2001), Reed *et al.* (2017) stated that the neurophysiological effects of SMT enhances spinal mobility, joint mobility, and stimulates muscle spindles afferents.

The findings in this study show that thoracic SMT positively influenced thoracic ROM in both males and females. In comparison between males and females, lumbar manipulation enhanced RLF and LLF in males and all thoracic ROM in females except for forward flexion. According to Hansen *et al,* 2009 oestrogen (hormone in females) improves the functioning of muscles, tendons, and ligaments.

5.5.2 Lumbar Range of Motion (ROM)

Table 4.11 and **Graph 4.2** showed there were statistically significant changes in forward flexion in both male (*p* values 0.004 and 0,005) and female (*p* values 0,028 and 0,008) participants post thoracic and lumbar spine manipulation. These changes imply that both thoracic and lumbar manipulation affect forward flexion in the lumbar spine. This is entirely due to the components of the thoracolumbar fascia, erector spinae, spinalis, quadratus lumborum, latissimus dorsi and multifidus which attach to the thoracic and lumbar spine, ribs and sacrum (Sanchez-Zuriaga, Adams and Dolan 2010). There were no significant changes visible post placebo manipulations.

According to Sanchez-Zuriaga, Adams and Dolan 2010, spinal movements are dependent on the sensorimotor mechanisms which are initiated by mechanoreceptor afferents. These afferents are found in several spinal tissues (muscles, IVD, ligaments and thoracolumbar fascia). The afferents in the disc and joint capsule have a high mechanical threshold and are activated under severe loading. The small muscles of the back have high density muscle spindles compared to long poly segmental muscles, thus they play an important role in the control of spinal movements (Sanchez-Zuriaga, Adams and Dolan 2010).

According to **Table 4.12** and **Graph 4.2,** there was no statistical difference between the three interventions in extension of the lumbar spine in the male (*p values* >0.05)

Table 4.13 and **Graph 4.2** showed that the three intervention groups had no statistically significant changes in thoracic and lumbar ROM (*p* values >0.05). However this differed in females, as both thoracic and lumbar SMT enhanced RLF (*p* values 0,006 and 0,005). There were no changes post placebo manipulation. The above statements imply that both thoracic and lumbar spine manipulation positively influence RLF in female participants as compared to males. This finding correlates with Moore (2001), that females have a greater joint mobility.

However, there is a significant difference between males and females for pre RLF L/S ROM (p = 0.002). It is noted in **Table 4.14** that the mean pre RLF L/S ROM for females was higher than that for males: 20.93 ± 2.46 vs 18.50 ± 3.43. The above statement is correct as the relevant literature and studies support the present evidence. According to Sullivan *et al.* (1994), van Herp *et al.* (2000) and Moore *et al.* (2001), females exibited greater joint mobility; especially in lateral flexion of the lumbar spine, when compared to males between the ages of 20-29 years.

As presented in **Table 4.15** and **Graph 4.2**, there were no statistically significant changes in LLF post thoracic spine, lumbar spine and placebo manipulation in male participants (*p* values 0,434, 0,080 and 0,257). However, in the female participants, LLF significantly changed post thoracic and lumbar spine manipulation (*p* values 0,009 and 0,004). There was no difference post placebo manipulation.

Post thoracic and lumbar manipulation revealed statistically significant changes in right rotation (**Table 4.16** and **Graph 4.2**) in both male *p* values (0,014 and 0,008) and female *p* values (0,006 and 0,004). There were no statsitically signifciant differences in both genders post placebo.

Intervention groups 1 and 2 significantly influenced lumbar rotaion in both male and female participants (p value <0.05). This occurred due to the closed relationship of the thoracolumbar fascia and other small back muscles that assist in spinal mobility (Sanchez-Zuriaga, Adams and Dolan 2010). SMT applied at the segmental vertebrae resulted in the release of adhesions, release of trapped meniscoids, and reduction in the annulus distortion. There were no differences post placebo manipulation

In summary, the thoracolumbar fascia is a layer of connective tissue that encloses the intrinsic muscles (superficial, intermediate, and deep layer) of the back and is situated between the thoracic and lumbar region. The intrinsic muscles intermediate layer (erector spinae; iliocostalis, longissimus and spinals) are the chief extensors of the vertebral column and aids in lateral flexion, and the deep layer (transverospinalis; semispinalis, multifidus and rotatores) are the chief stabilisers (multifidus) of the vertebral column and assists with local extension and rotation (Moore, Dalley and Agur 2010). According to Sanchez-Zuriaga, Adams and Dolan 2010 the thoracolumbar fascia contains mechanoreceptor afferents within it that permits the reflex action of the spinal movements. The small segmental muscles of the back have muscle spindles and together with the thoracolumbar fascia play a vital role in spinal mobility.

The thoracolumbar fascia plays an important role in the stability and movement of the lumbar and thoracic spine. There would be increased tension and decreased ROM in the lumbar and thoracic spine if there was contraction in the above-mentioned muscles or fascia. The rotatory motion of the lumbar SMT, coupled with extension, decreases the tension within the fascia, and thus results in increased ROM in both male and female participants (Willard *et al.* 2016).

5.6 THE EFFECT OF PLACEBO MANIPULATION ON THORACIC AND LUMBAR ROM

The use of placebo manipulation showed no statistically significant changes to the various trunk ROM findings, as indicated by **Table 4.5** to **4.17**. The findings in this study are similar to that of Sood (2008); Deutshmann (2015) and Robson (2018). The only difference is that a placebo manipulation compared to sham laser was conducted in this study, which is like manipulation.

The findings (**Tables 4.31** to **4.36)** in this study support the conclusions postulated by several authors (Ruddock *et al.,* 2016; Hancock *et al.* 2006), that spinal manipulation is superior to sham manipulation.

The participants in Group 3 did not know that they were in a non-active, intervention group. Therefore, this allowed the researcher to measure the physical effects independently of participants' perception (Draper 2002). The placebo method used was similar to that of the active intervention, i.e. patient lay prone with the area of interest exposed. The placebo manipulation showed no statistically significant effect on bowling speed.

5.7 THE AVERAGE BOWLING SPEED

According to **Table 4.18** and **Graph 4.3**, the bowling speed for males is higher than that for females. In both genders, there are differences in the pre speed vs post speeds. The significance of the differences are tested and shown in **Table 4.18**. Concerning post thoracic spine manipulation, there were statistically signficant changes in bowling speed in both male (*p* value 0,005) and female (*p* value 0,005) participants. There are two types of analysis that can be done for each variable: one compares pre vs post within each gender separately, and the other compares the type (of intervention) within males only. This is done similarly for females.

According to **Table 4.37**, which compares the change in bowling speed between the three interventions, thoracic manipulation (Group 1) significantly impacted bowling speed in comparison to lumbar manipulation

(Group 2) (*p* value 0,963) and placebo spinal manipulation (Group 3). Type 3 is the reference group. Lumbar manipulation has no statistically significant impact on bowling speed when compared to placebo manipulation (Group 3). According to **Graph 4.3,** bowlers in the placebo group had higher bowling speeds pre and post manipulation, as compared to those in the lumbar manipulation group. The above finding implies that post thoracic SMT, bowling speed significantly increased in reference to comparisons between groups 1 – 3 (thoracic, lumbar and placebo). According to **Table 4.37**, the thoracic SMT partial Eta squared value of 0.515 implies that thoracic SMT had the largest effect on bowling speed in comparison to lumbar and placebo SMT

Incidentally, irrespective of gender, the older the bowler (25-29 years), the taller the bowler (1.7-1.79m) and lighter (60-79kg) the bowler was, were all factors that increased bowling speed. This finding correlates with the findings of Felton *et al*. (2018) who stated that the taller, lighter, and more experienced (older) the bowler is the greater the ball speed is.

5.8 BOWLING SPEED AND THORACIC AND LUMBAR ROM

The baseline mean values (SD) for bowling speed pre and post intervention are presented in **Table 4.18** and **Graph 4.3**. These values lie within the normal range of 85-125 km/h for indoor cricket fast bowlers.

Concerning post thoracic spine manipulation, there were statistically signficant changes in bowling speed in both male (*p* value 0,005) and female (*p* value 0,005) participants. There are two types of analysis that can be done for each variable: one compares pre vs post within each gender separately, and the other compares the type (of intervention) within males only. This is done similarly for females.

Thoracic Manipulation – Group 1a and 1b

The mean speed for Groups 1a and Group 1b as indicated in **Table 4.18** and **Graph 4.3,** pre intervention 90.39 km/h, post intervention 94.74 km/h and *p* value (0,005). For Group 1b, pre intervention was 75.95 km/h and post intervention was 79.47 km/h, *p* value (0,005). The above-mentioned tables depict that thoracic spine manipulation significantly increased bowling speed in both male and female participants. Bowling speed, thoracic ROM, and lumbar ROM had a directly proportional relationship post thoracic SMT. The findings correlate with that of Sood (2008), Robson (2018).

Lumbar Manipulation – Group 2a and Group 2b

The mean speed for Group 2a as indicated in **Table 4.5** and **Graph 4.3** pre intervention was 85.42 km/h, and post intervention was 85.54 km/h, *p* value (0.539). Group 2b, pre intervention was 69.44 km/h, and post intervention was 69.38 km/h, *p* value (1.000). The above-mentioned tables state that lumbar spine manipulation showed no significant change in bowling speed in male and female participants. However, lumbar SMT influenced ROM in male and female participants. Bowling speed and ROM have an inverse relationship post lumbar SMT, as range of motion increased, bowling speed decreased post lumbar SMT.

Placebo Spinal Manipulation – Group 3a and 3b

The mean speed for Group 3a and Group 3b as indicated in **Table 4.5** and **Graph 4.3** is as follows: pre-intervention was 86.06 km/h, and post intervention was 86.19 km/h, *p* value 0.339. For Group 3b, pre-intervention was 78.88 km/h, post intervention was 86.19 km/h, *p* value 0.157. Placebo manipulation, which was a sham therapy showed no influence on bowling speed in both male and female participants. Thus, correlating with the statement mentioned previously that SMT is superior to sham manipulation. Placebo SMT was the sham therapy that focused on the psychological effects of SMT and not the physiological effects.

The following patterns were observed:

- The bowling speeds for males was higher than that for females.
- In both genders, there were differences in the pre vs post speeds.
- The significance of the differences has been tested and shown in the **Table 4.18** and **Graph 4.3.**

This significant differences is due to the physical charateristics and changes in biomechanics. Felton *et al*. 2018 stated that females bowled slower and released the ball at a slower rate due to them having a short torso, arm lengths and height when compared to male participants. When looking at back foot contact females had a lower horizontal centre of motion, more flexed hips, reduced upper trunk flexion; at front foot contact and ball release, females had a front on pelvis and shoulder orienation, an increase in upper trunk flexion, and a greater delay in the bowling arm, thus resulting in a slower ball release speed.

When comparing the change in average bowling speed between male and female participants across the 3 intervention groups (thoracic, lumbar, and placebo) the results were statistically insignificant, thus implying that gender has no impact on the change in bowling speed.

The average bowling speeds that were recorded in this study differed to those that were presented by Sood (2008). Factors like height, weight and gender contributed to these differences found.

In summary, thoracic spine manipulation showed greater increases in bowling speed in both male and female indoor cricket bowlers, as compared to lumbar and placebo manipulation. The findings reported in this study supports the theories postulated by several authors (Meister 2000; Stodden *et al.* 2005; Seroyer *et al* 2010), that the thoracic spine ROM facilitates the bowling action. The influence of the thoracic spine on the glenohumeral joint and scapulothoracic position permits the scapula to protract and rotate during the arm cocking and deceleration phase, thus contributing to an increase in bowling speed post manipulation (Seroyer *et al* 2010).

5.9 RELATIONSHIP BETWEEN CHANGE IN BOWLING SPEED AND ROM

According to **Tables 4.20, and 4.23**, there are significant changes that occurred between the change in thoracic and lumbar ROM and the change in participants bowling speed post thoracic spine manipulation in both male and female participants. The evidence presented in the above tables show a directly proportional (one variable increase and the same occurs to the other variable) relationship between ROM and bowling speed. There were enhances in thoracic ROM, lumbar ROM, and bowling speed post thoracic spine manipulation. However, this is exception to RLF of the thoracic spine and RLF and LLF of the lumbar spine in males and RPA of the thoracic spine and extension of the lumbar spine in females.

When looking at **Tables 4.26 and 4.29**, there were statistically significant changes visible between change in spinal ROM and the change in participants bowling speed post lumbar manipulation in both males and females. The evidence presented in the tables show an inversely proportional (one variable increases, and the other variable decreases or has no change) relationship. There were increases in the thoracic ROM and lumbar ROM, however there were no changes visible in bowling post lumbar manipulation. However, with exception of thoracic spine extension and lumbar spine RLF in males. The only significant change in the female participants were extension, RLF, RPA of the thoracic spine and RLF of the lumbar spine.

According to **Tables 4.32 and 4.36**. there were statistically significant changes post placebo manipulation. Placebo manipulation should not bring about a change in ROM or bowling speed, as it was a sham (no manipulation) therapy. This correlates with the Null Hypothesis mentioned in Chapter 1, there would be no statistically significant relationship between immediate change in bowling speed post intervention and an immediate change in range of motion of the lumbar spine and/or thoracic spine.

Thus, the above statements partially accept the Null Hypothesis (stated in 1.2.1 in chapter one) which stated that, there is no significant change in bowling speed and spinal range of motion post manipulation or intervention.

Thoracic spine position influences the glenohumeral joint and scapulothoracic position. The position of the thoracic spine affects scapula kinematics, thus resulting in decreased muscular forces. In this study thoracic ROM significantly increased and showed a positive enhancement on bowling speed post manipulation.

Stodden *et al.* (2005) and Seroyer *et al.* (2010) concluded that during the late cocking phase; as the upper trunk rotated, forward and laterally flexed, the pectoralis major and anterior deltoid muscle moved the bowling arm into a horizontal adduction position to facilitate ball release.

The activation of the kinetic chain transmits and generates the force required for the bowling action into the pelvis and spine (Gilchrist, Frey, and Nadler 2003). The thoracic spine contributes 50% of kinetic force and energy during the bowling motion. According to several authors (Stodden *et al*. 2005; Seroyer *et al.* 2010), the trunk and lower extremity act as stabilizers and generate the force and energy required for the bowling action in the kinematic chain.

As stated by Seroyer *et a*l. (2010), the kinetic and kinematic factors and segmental body movements contribute to the bowling motion and ball velocity. There are several factors that affect bowling speed (run up speed, front knee extension, arm position, pelvic-shoulder girdle separation angle and trunk motion), as stated in Chapter 2. The above coupled actions are essential for bowling and ball release speed. A coupled action of increased pelvic and upper torso rotation, thoracic FF, increased shoulder, and elbow proximal forces enhances ball release speed (Stodden *et al.* 2005).

Stodden *et al.* (2005) concluded that the core musculature, trunk, and lower extremity in the kinetic chain reduced the kinetic contributions of the glenohumeral joint in the bowling action and thoracic forward flexion permitted a greater ball velocity. He furtherly postulated that bowlers should strengthen the upper extremity and strengthen and improve trunk mobility and flexibility to maximise bowling velocity and focus on consistent mechanics to produce consistently high fastball velocities.

In this study it was clearly visible that thoracic manipulation had a directly proportional relationship on bowling speed and spinal range of motion in both male and female participants. Post thoracic manipulation both bowling speed and range of motion increased.

5.10 THE PARTICIPANTS' PERCEPTIONS OF CHANGE IN BOWLING SPEED

As reported in **Table 4.38** and **Table 4.39,** the Fisher Comparison test was used to determine the relationship between change in bowling speed pre and post intervention and the participants' perception of change in bowling speed. The *p* value for male (0,035) and female (0,0072) participants showed there is a significant relationship that exits between the group from which the participants are and their perception.

According to the evidence reported in **Table 4.38**, overall, 12 (40%) of the male participants were perceived or believe they experienced an increase, 7 participants (23.33%) perceived a decrease and 11 (36.66%) perceived no change. In Group A, 70% of participants perceived an increase, 10% perceived a decrease and 20% perceived no change. In Group B, 40% of participants perceived an increase, 40% perceived a decrease and 20% perceived no change. In Group C, 10% of participants perceived an increase, 20% perceived a decrease and 70% perceived no change.

The above stated table provides the overall information of subjective change in bowling speed in male participants. The subjective findings correlate with the objective findings within this study. Group A (thoracic manipulation) significantly enhanced bowling speed as compared to Group B (lumbar manipulation) and Group C (placebo manipulation).

The evidence presented in **Table 4.39** presents the overall perception of the female participants: 11 (36.66%) of participants perceived an increase, 3 (10%) perceived a decrease and 16 (53.33%) perceived no change. In Group A, 80% of participants felt an increase, 0% a decrease and 20% no change. In Group B, 20% perceived an increase, 20% a decrease and 60% no change. In Group C, 10% perceived an increase, 10% a decrease and 80% no change.

Table 4.39 explains the correlation between the subjective and objective findings of female participants within this study. As depicted in the table, Group A (thoracic manipulation) showed to have the most effect on bowling speed, as compared to Group B (lumbar manipulation) and Group C (placebo manipulation). This finding correlates with actual findings of this study, where thoracic manipulation influenced both bowling speed and range of motion in the participants.

According to Bergman and Peterson (2010), the audible click, pop, crack or snap, the physical contact associated with SMT, and mechanical effects of SMT (Pickar 2002 and Reed et al. 2017) were the factors that influenced participants' perception in their change in bowling speed. Post spinal manipulations, in both groups, male and female, the participants felt much looser. They felt their bowling techniques were much smoother. The above statements correlate with that of Korr 1976, Pickar (2002) and Reed *et al*. 2017, who explained the neurophysiological effects of SMT.

The participants in Group 1a and Group 1b and Group 2a and Group 2b experienced the most change in bowling speed, as evident in **Tables 4.19, 4.22, 4.25** and **4.28**, However, Group 2a and Group 2b participants did not have a significant change in bowling speed as compared to Group 1a and Group 1b in correlation with their perception. Group 3a and Group 3b participants believed their bowling speed remained the same, as many of the participants felt the placebo manipulation did not have much force or pressure, as shown in **Tables 4.38** and **Table 4.39**.

The above findings correlate with the Null Hypothesis mentioned in chapter 1, that there would be no changes, objective and subjective in bowling speed or range of motion post thoracic manipulation, lumbar manipulation, and placebo manipulation. However, as shown in the study, post thoracic manipulation had a significant effect on both bowling speed and range of motion in asymptomatic male and female participants both objectively and subjectively. Lumbar manipulation had shown no significant changes in bowling speed, however there were increases in some ranges of motion in the thoracic and lumbar spines. Placebo manipulation, being a sham therapy supported the Null hypothesis mentioned in chapter 1. This manipulation showed no effect on change, objectively or subjectively in both bowling speed and range of motion in male and female participants.

In conclusion, it has been proven that there is a statistically significant association between bowling speed pre-intervention and post-intervention and participants' perception of a change in bowling, thus partially rejecting the Null Hypothesis (4) stated in Chapter 1.

Thoracic manipulation was shown to influence bowling speed compared to lumbar manipulation and placebo manipulation. The finding in this study was perceived by the participants as well.

5.11 CONCLUSION

The above study assessed the effect of lumbar spine, thoracic spine, and placebo manipulation on range of motion and bowling speed in asymptomatic male and female cricket bowlers. Within the male and female intervention groups there were similarities in demographics and physical characteristics and thus, data biasness was eliminated in this study.

The Saunders digital inclinometer is a measuring tool that has both intra and inter observer reliability of measurements. This tool was used to measure the objective ROM of the thoracic and lumbar spine in male and female participants. The findings reported in this study correlates with the studies conducted by Sood (2008); Deutschmann (2015); Wigget (2015) and Robson (2018). The above-mentioned researchers assessed the effect of spinal manipulation on spinal range of motion and athletes' performances.

According to findings in this study, spinal manipulation positively influenced thoracic and lumbar range of motion. SMT is a treatment method which has been widely used on symptomatic and asymptomatic individuals and as an athlete performance enhancer (Costa *et al.* 2009; Humphiries *et al.* 2013). Stone (2001) postulated that an athlete would benefit from SMT, irrespective of being symptomatic or asymptomatic, due to the biomechanics and kinetics of the spine.

The findings in this study showed that thoracic SMT positively influenced both bowling speed and thoracic and lumbar ROM in both male and female participants as compared to lumbar SMT which only influenced ROM and placebo SMT, which showed no significant relationship between bowling speed and thoracic and lumbar ROM.

An important finding was that thoracic SMT increased both thoracic and lumbar ROM and lumbar SMT had the similar effect. This finding correlates with the studies completed by Sood (2008), Deuctshman (2015), Robson (2018). This finding shows that SMT causes a holistic effect on ROM and is not entirely dependent on the segment or region where manipulation is applied. This occurs primarily due to the neurophysiological effects of SMT.

Findings in this study show that SMT enhances bowling speed, thus enhancing athlete performance. This finding correlates with the literature mentioned in chapter 2 on the neurophysiological effects of SMT on the spine and its effect on athlete's performance. This study supports the statement and finding of other literature that SMT is superior to placebo therapy. According to this study thoracic SMT has been shown to be superior to lumbar and placebo SMT on change in bowling speed.

The current study investigated that the optimum method for fast bowling is comparable to standing throws (javelin). The results in this study found significant differences in bowling speed and kinematics in males and females, which may indicate that females use a different technique or due to the differences in biomechanics or physical changes to generate ball speed. Therefore, even if females could match the bowling speeds of males and produce the similar kinematics for each segment, they would still produce a slower bowling speed since females have proportionally shorter arms and torso due to their shorter body height.

In summary, cricket fast bowling technique requires flexion, lateral flexion, rotation, and extension of the thoracic and lumbar spine to facilitate ball release and generate a high ball velocity. The coupled motion of thoracic flexion, rotation, and shoulder external rotation allows for a greater force to be applied to the ball, thus producing a high ball release speed or velocity (Seroyer *et al.* 2005).

The findings in this study prove that thoracic spine manipulation positively influenced bowling speed in both male and female participants, in comparison to lumbar and placebo manipulation. The findings reported correlates with the findings of several authors (Meister 2000; Stodden *et al.* 2005; Seroyer *et al*. 2010), that the thoracic spine ROM facilitates the bowling action. The influence of the thoracic spine on the glenohumeral joint and scapulothoracic position permits the scapula to protract and rotate during the arm cocking and deceleration phase, thus contributing to an increase in bowling speed post manipulation (Seroyer *et al.* 2010).

The kinematic, kinetic, and temporal variation in the bowling motion are shown to be related to improve velocity and force generation. To produce a great velocity, the bowler needs to optimise the coordinated use of muscle segments throughout the body to generate and transfer potential energy to the upper extremity for conversion into kinetic energy for ball release. As there were statistically significant increases in trunk FF, extension and RLF, these finding correlates with statements made by previous authors (Stodden 2005; Weber 2014; Meister 2000) that spinal or trunk kinetics enhance bowling speed post manipulation.

Therefore, the findings in this study depict that males and females respond biomechanically differently to thoracic and lumbar manipulation, but, however, they show the same change in bowling speed.

CHAPTER 6: CONCLUSION

6.1 AIM OF THE STUDY

The aim of the study was to determine, via a controlled, prospective clinical trial, the relative effectiveness of thoracic, lumbar, and sham manipulation on range of motion and bowling speed in asymptomatic indoor cricket bowlers registered in the KZNCU.

The two manipulative groups showed to be more effective than the placebo manipulation group in enhancing range of motion and bowling speed. The thoracic manipulation group achieved the greatest increase in ROM and bowling speed changes.

6.2 OBJECTIVES

Objective One

Lumbar manipulation positively influences lumbar ROM, especially in females. It is evident that lumbar manipulation affects thoracic ROM positively. Lumbar spinal manipulation has no significant effect on bowling speed in both male and female participants.

Objective Two:

Thoracic spine manipulation is statistically significant in enhancing thoracic ROM in male and female participants, as well as lumbar FF in males, and RLF, LLF, RPA and LPA in females. Thoracic spine manipulation enhances bowling speed in both genders.

Objective Three:

The thoracic and lumbar ROM and bowling speed showed no statistical significance post placebo manipulation in male and female participants.

Objective Four:

There was a statistically significant change associated between the change in bowling speed pre and post intervention and participant’s perception on change in bowling speed.

6.3 NULL HYPOTHESIS

One:

There would be no statistically significant increases in bowling speed post intervention for any of the three groups. This is partially accepted as there was a statistically significant change in bowling speed post thoracic manipulation, but there were no changes post lumbar and placebo manipulation.

Two:

There would be no statistically significant increases in range of motion for any of the three groups. This is partially accepted, as there were significant increases in thoracic and lumbar ROM post manipulation. However, there were no changes post placebo manipulation.

Three:

There would be no statistically significant relationship between change in bowling speed immediately post intervention and change in range of motion of the lumbar spine and/or thoracic spine. Forward flexion, extension, RLF and LLF were significantly changed post manipulation, with a corresponding change in bowling speed visible. Thus, this null hypothesis is partially accepted.

Four:

There would be no statistically significant relationship between change in bowling speeds immediately post intervention and the participants' perception of change in bowling speed. There is a relationship between the group the participants were in and their perception, and, thus, this hypothesis is partially accepted.

6.4 SUMMARY

The results of this study indicate that SMT positively impacts indoor cricket bowlers bowling speed, irrespective of gender. The neurophysiological benefits of SMT on all thoracic and lumbar ROM correlated with the findings of several authors. This study showed that the ROM between male and female indoor cricket bowlers increased post manipulation, as females showed a significant increase post lumbar and thoracic manipulation. This could be due to females having a greater joint mobility and flexibility in the sagittal and coronal planes (Sullivan *et al,* 1994 and van Herp *et al.* 2000) as well as due to higher oestrogen levels than males (Hansen *et al.* 2009).

According to Stump (2001), SMT positively influences asymptomatic athletes' performance and this study correlated with the above statement. However, more extensive studies and research should be conducted to expand on the current knowledge and evidence that is available on SMT and its effect on athletes' performances. This would enable chiropractic professionals to manage indoor cricket bowlers effectively and differently (to non-competitive individuals).

Strengths

Availability of participants as the study was conducted during the cricket season. Both males and females had similar experience and time within the professional training environment throughout development.

Limitations

Age group between 18-45 years. The oldest individual used in the study was 38 years old. Biomechanically and physically this individual differed from the younger population. Speed radar gun and digital inclinometer was not readily available. If this is available much sooner for the research it makes the research process run smooth and efficiently. There were not many public indoor facilities available, thus affecting data collection as it could only be done in two areas (Chatsworth Oval and Kingsmead stadium). Registering the clinical trial with the National Health Research Committee took 6 months due to strikes at the Department of Health (DOH).

6.5 RECOMMENDATIONS

- A similar study can be conducted on other overhead athletes (javelin throwers, tennis players), to assess if there is a difference in biomechanics, or do all overhead athletes have the same biomechanics.
- Assess the neurophysiological benefits of cervical spine manipulation on throwing or bowling speed, due to the close relationship between the cervical spine and glenohumeral joint (SMT produces the most benefits in the cervical spine region) (Milan *et al.* 2012).
- A study should be conducted on a younger group of participants, ages 13- 18, to assess the change in biomechanics with age as a factor
- A similar study can be conducted but inclusive of the effects of demographics and physical characteristics. To assess whether either of the above-mentioned factors influence bowling speed, especially height and weight.
- A similar study could be conducted, but look at the difference in techniques (mixed, front-on or side-on) and its effect on bowling speed.
- This study was conducted on amateur indoor cricket bowlers. A future study could be done on professional indoor cricket bowlers, to assess if there is a difference between professional and amateur cricket and could this be related to technique or high endurance workload.
- A study assessing the effects of muscular trigger points and creep on the muscles of the back or shoulder and its effect on throwing speed in overhead athletes. The finding of this study will assist medical professionals in the treatment and management of such patients.

REFERENCES

Aguinaldo, A. L., Buttermore, J. and Chambers, H. 2007. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *Journal of Applied Biomechanics*, 23(42-51)

Ali, F. and Dublin, A. B. 2018. *Anatomy, Back, Anterior spinal artery*. Treaure Island: Stat Pearls.

Bergmann, T. F. and Peterson, D. H. 2010. *Chiropractic Techniques: Principles and Procedures*. 3rd ed. New York: Mosby, Inc.

Bialosky, J. E., Bishop, M. D. and Robinson, M. E. 2011. Placebo response to manual therapy: something out of nothing? *Journal of Manual and Manipulative Therapy*, 19 (1): 11-19.

Botelho, M. B. a. and Andrade, B. B. 2012. Effect of cervical spine manipulative therapy on judo athletes' grip strength. *Journal of Manipulative Physiological Therapeutics*, 35(1): 38-44.

Bucke, J., Fawcett, L. and Rushton, A. (2017). Validity of the digital inclinometer and iphone when measuring thoracic spine rotation. Journal of Athletic Training, 52 (9): 820-825.

Brosnan, C. 2017. Alternative futures: Fields, boundaries, and divergent professionalisation strategies within the Chiropractic profession. *Social Science & Medicine*, 190: 83-91.

Burkhart, S. S., Morgan, C. D. and Kibler, B. W. 2003. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. Arthroscopy. *The Journal of Arthroscopic & Related Surgery*, 19(4): 404-420.

Calabrese, G. J. 2013. Pitching mechanics, revisited. *International journal of sports physical therapy*, 8(5): 652-660.

Callender, A. A. and Wiese, G. 2005. History of spinal manipulation. In: Haldeman, S. ed. *Principles and practice of chiropractic*. *Spine Journal*, 3rd ed.

Chu, S. K., Jayabalan, P., Kibler, W. B. and Press, J. 2016. The Kinetic Chain Revisited: New Concepts on Throwing Mechanics and Injury. *Pm r*, 8(3 Suppl): S69-77.

Chu, Y., Fleisig, G. S., Simpson, K. J. and Andrews, J. R. 2009. Biomechanical comparison between elite female and male baseball pitchers *Journal of Applied Biomechanics*, 25(1): 22 - 31.

Clark, B. C., Walkowski, S., Conatser, R. R., Eland, D. C. A. and Howell, J. N. 2009. Muscle functional magnetic resonance imaging and acute low back pain: a pilot study to characterize lumbar muscle activity asymmetries and examine the effects of osteopathic manipulative treatment. *Journal of Osteopath Medicine*, 7.

Cooperstein, R., Haneline, M. and Young, M. 2010. Interexaminer reliability of thoracic motion palpation using confidence ratings and continuous analysis. *Journal of Chiropractic Medicine*, 9(3): 99-106.

Costa, S. M., Chibuna, Y. E., Giavarotti, L., Compagnoni, D. S., Shino, A. H., Satie, J. a. and Bracher, E. S. 2009. The effect of spinal manipulation with strengthening compared to strengthening alone of full swing performance of golfers: a randomized pilot study. *Journal of Chiropractic Medicine*, 8(4): 165-170.

Crewe, H., Elliott, B., Couanis, G., Campbell, A. and Alderson, J. 2012. The lumbar spine of the young cricket fast bowler: an MRI study. *J Sci Med Sport*, 15(3): 190-194.

David, T. 2008. The 17th century game of cricket. A reconstruction of the game*. Sports Historian*, 20: 33-43.

Davis, K. and Blanksby, B. 1976. A cinematographical analysis of fast bowling in cricket. *Australian Journal for Health, Physical Education and Recreation*, 71: 9-15.

Deutschmann, K. C. 2015. The Immediate Effect of Sham Laser and Three Different Spinal Manipulative Protocols on Kicking Speed in Soccer Players. Master's Degree in Chiropractic, Durban University of Technology.

DeVocht, J. W., Pickar, J. G. A. and Wilder, D. G. 2005. Spinal manipulation alters electromyoFigureic activity of paraspinal muscles: a descriptive study. *Journal of Manipulative Physiological Therapeutics*, 28(7): 465-471.

DeVocht, J. W., Smith, D. L., Goertz, G. M., Long, C. R., Lorber, L., Kane, B., Jones, T. M. (2016). The effect of chiropractic treatment on the reaction time and response times of special operation forces military personnel: study protocol for a randomised clinical trial.

Deyo, A. R. 2017. The role of spinal manipulation in the treatment of low back pain. Spinal Journal, 317 (14): 343-354.

Draper, S. W. 2002. *The Hawthorne, Pygmalion, Placebo and Other Effects of Expectation: Some Notes*. [online] Available: Available from: http://www.psy.gla.ac.uk/~steve/hawth.html (Accessed 20 September 2007).

Ebraheim, N. A., Hassan, A., Lee, M. and Xu, R. 2004. Functional anatomy of the lumbar spine. *Seminars in Pain Medicine*, 2(3): 131-137.

Elliott, B. and Khangure, M. 2002. Disk degeneration and fast bowling in cricket: an intervention study. *Med Sci Sports Exerc*, 34(11): 1714-1718.

Engel, R., Dawe, N. and Edwards, S. 2017. The effect of thoracic spinal manipulation on trunk motion in elite sprint kayakers: a pilot crossover trial. *Journal of Science and Medicine in Sport*, 20: 20-33.

Gatterman, M. I. 2004. Chiropractic management of Spine Related Disorders. *Journal of the Canadian Chiopractic Association*, 48(4): 313.

Felton, P. J., Lister, S. L., Worthington, P. J. and King, M. A. 2018. Comparison of biomechanical characteristics between male and female elite fast bowlers. *Journal of Sports Sciences*, 37 (6): 1-6.

Ferdinands, R. E. D., Kersting, U. and Marshall, R. N. 2009. Three-dimensional lumbar segment kinematics of fast bowling in cricket. *Journal of Biomechanics* 42 (11): 1616-1621.

Gilchrist, R. V., Frey, M. E. and Nadler, S. F. 2003. Muscular control of the lumbar spine. *Pain Physician*, 6(3): 361-368.

Glazier, P. S., Paradisis, G. P. and Cooper, S. M. 2000. Anthropometric and kinematic influences on release speed in men's fast-medium bowling. *Journal of Sports Sciences*, 18: 1013-1021.

Hadler, N. M., Curtis, P., Gillings, D. B. A. and Stinnett, S. 2007. A benefit of spinal manipulation as adjunctive therapy for acute low-back pain: a stratified controlled trial. *Spine Journal*, 12: 703-706.

Hancock, M., Maher, C., Latimer, J. and McAulley, J. 2006. Selecting an appropriate placebo for a trial of spinal manipulative therapy. *Australian Journal of Physiotherapy*, 52: 135-138.

Hirashima, M., Yamane, K., Nakamura, Y. and Ohtsuki, T. 2008. Kinetic chain of overarm throwing in terms of joint rotations revealed by induced acceleration analysis. *Journal of Biomechanics*, 41(13): 2874-2883.

Hoiriis, K. T., Pfleger, B., McDuffie, F. C., Cotsonis, G., Elsangak, O., Hinson, R. and Verzosa, G. T. 2004. A randomized clinical trial comparing chiropractic adjustments to muscle relaxants for subacute low back pain. *J Manipulative Physiol Ther*, 27(6): 388-398.

Hoskins, W. A. and Pollard, H. 2010. The effect of sports chiropractic manual therapy intervention on prevention of back pain, hamstring lower limb injuries in semi-elite Australian Rules footballers. *Journal of Chiropractic Osteopathy*, 18(23).

Howell, J. N., Karen, S., Cabell, D. O., Anthony, G., Chila, D. O., David, C. A. and Eland, D. O. 2006. Stretch reflex and Hoffmann reflex responses to osteopathic manipulative treatment in participants with Achilles tendinitis. *Journal of American Osteopath*, 106(9): 537-545.

Hughes, S. 2001. *Jargonbusting: An Analyst's Guide to Test Cricket*. London: Channel 4 Books.

Humphiries, K. M., Ward, J., Coats, J., Nobert, J., Amonetter, W. M. A. and Dyess, S. 2013. The immediate effect of lower cervical spine manipulation on handgrip strength and free throw accuracy in asymptomatic basketball players: a pilot study. *Journal of Chiropractic Medicine*, 12(3): 153-159.

Hurrion, P. and Harmer, J. 2002. *The Fast-Medium Bowler Sports Biomechanics and Technical Analysis Model*. Available: http://coachesinfo.com/index.php?option=com_content&view=article&id=281:fastmedium&catid=84:cricket-bowling&Itemid=159(Accessed 1 October, 2018).

James, D., Carré, M. and Haake, S. 2005. Predicting the playing character of cricket pitches. *Sports Engineering*, 8: 193-207.

Jarosz, B. S. A. and Elliot, W. B. 2010. The effect on race walkers' sports performance with chiropractic treatment: a case report. *Journal of Chiropractic Manipulation*, 40: 117-119.

Jaumard, N. V., Welch, W. C. and Winkelstein, B. A. 2011. Spinal Facet Joint Biomechanics and Mechanotransduction in Normal, Injury and Degenerative Conditions. *Journal of Biomechics*, 133(7): 71010.

Jermyn, G. J. 2004. The immediate effect of spinal manipulative therapy on club head velocity in amateur golfers suffering from mechanical low back pain. Master's Degree in Chiropractic, Durban Institute of Technology.

Kamali, F., Sinaei, E. and Bahadorian, S. 2017. The immediate effect of talocrural joint manipulation on functional performance of 15e40 years old athletes with chronic ankle instability: A double-blind randomized clinical trial. *Journal of Bodywork & Movement Therapies*, 21: 830-834.

Kawchuk, G. N., Fryer, J., Jaremko, J. L., Zeng, H., Rowe, L. and Thompson, R. 2015. Real-time visualization of joint cavitation. *Public Library of Science*, 10 (4)

Keller, T. S. A. and Colloca, C. J. 2000. Mechanical force spinal manipulation increases trunk muscle strength assessed by electromyography: a comparative clinical trial. *Journal of Manipulative Physiological Therapeutics*, 23(9): 585-595.

Kelly, D. D., Murphy, B. A., Backhouse, D. P. and Grimston, S. K. 2000. Muscular rehabilitation prescribed in coordination with prior chiropractic therapy as a treatment for sacroiliac subluxation in female distance runners. *Journal of Chiropractic Sports Medicine*, 2-3.

Kelsick, W. E. 2003. The pre-participation examination. *Journal of Canadian Chiropractic Association*, 8(5): 6,8,9,33.

Kibler, W. B., Press, J. and Sciascia, A. T. 2006. The role of core stability in athletic function. *Journal of Sports Medicine*, 36(189-198).

Konczak, C. R. 2010. Chiropractic utilization in BMX athletes at the UCI World Championships: a retrospective study. *Journal of Canadian Chiropractic Association*, 54(4): 250-256.

Korr, I. M. 1976. Proprioceptors and the behaviour of lesioned segments In: Stark E.H. ed. *Osteopathic Medicine*. Action MASS: Publication Sciences group. 183-199.

Kriel, A. 2004. An investigation into the immediate effect of rib mobilisation and sham laser application on chest wall expansion and lung function in healthy asymptomatic males. Master's Degree in Technology, Durban Institute of Technology.

Liebenberg, J. N. 2010. Kinetics at front foot contact of cricket bowling during a 10-over spell. Master’s Degree, University of Nevada, Las Vegas.

Liebsch, C. and Wilke, H.-J. 2018. Chapter 3 - Basic Biomechanics of the Thoracic Spine and Rib Cage. In: Galbusera, F. and Wilke, H.-J. eds. *Biomechanics of the Spine*. Available: http://www.sciencedirect.com/science/article/pii/B9780128128510000033 (Accessed 30 July 2018).

Maitland, G. D. 2001. *Vertebral Manipulation*. 5 ed. London Butterworth:

Millan, M., Leboeuf-Yde, C., Budgell, B., Descarreaux, M. and Amorim, M.-A. 2012. The effect of spinal manipulative therapy on spinal range of motion: a systematic literature review. *Chiropractic & manual therapies*, 20(1): 23-23.

Miners, A. L. 2010. Chiropractic treatment and the enhancement of sport performance: a narrative literature review. *Journal of Canadian Chiropractic Association*, 54(4): 210-221.

Moore, K. L., Dalley, A. F. and Agur, A. M. R. 2010. *Clinically Orientated Anatomy*. 6th ed. Baltimore: Wolters Kulwer Lippincott Williams and Wilkins.

Munro, C. and Christie, C., Jo-Anne. 2018. Research directions for the enhancement of women's cricket. *International Journal of Sports Science and Coaching*, 1: 1-5.

Newman, H. 2012. Factors affecting bowling speed in cricket. *Thoughts and reflections on key concepts within Sport and Exercise Science* (Blog). Available: https://hannahnewman91.wordpress.com/2012/11/19/factors-affecting-bowling-speed-in-cricket/ (Accessed 30 July 2018).

Nook, D. D. a. and Nook, B. C. 2011. A report of the 2009 World Games injury surveillance of individuals who voluntarily used the International Federation of Sports Chiropractic delegation. *Journal of Manipulative Physiological Therapeutics*, 34(1): 54-61.

Oliver, G. D. and Keeley, D. W. 2010. Gluteal muscle group activation and its relationship with pelvis and torso kinematics in high school baseball pitchers. *Journal of Strength and Conditioning Research*, 24(11): 3015-3011.

Oliver, G. D., Washington, J. K., Barfield, J. W., Gascon, S. S. and Gilmer, G. 2018. Quantitative Analysis of Proximal and Distal Kinetic Chain Musculature During Dynamic Exercises. *J Strength Cond Res*, 32(6): 1545-1553.

Pickar, J. G. 2002. Neurophysiological effects of spinal manipulation. *Spine Journal*, 2(5): 357-371.

Puhl, A. A., Reinhart, C. J., Doan, J. B. and Vernon, H. 2017. The quality of placebos used in randomized, controlled trials of lumbar and pelvic joint thrust manipulation—a systematic review. *The Spine Journal*, 17: 445-456.

Ranson, C. A. 2008. The relationship between bowling action classification and three-dimensional lower trunk motion in fast bowlers in cricket. *Journal of Sports Science*, 26 (3): 267-276.

Reed, W. R., Cyanthia, R. L., Gregory, N., Kawchuk, D. C., Randall, S., Sozio, B. S., Joel, G. and Pickar, D. C. 2017. Neural responses to physical characteristics of high velocity, low amplitude spinal manipulation. Spine Journal, 43 (1): 1-9.

Robson, M. 2018. The immediate effect of sham laser and three different spinal manipulative protocols on the throwing speed of baseball players in the Kwa-Zulu Natal Baseball Union. Master's Degree in Chiropractic, Durban University of Technology.

Rubinstein SM, van Middelkoop M, Assendelft WJJ, de Boer MR and MW., v. T. 2011. Spinal manipulative therapy for chronic low-back pain. *The Cochrane Library*, (2).

Ruddock, J. K., Sails, H., Ness, A. and Perry, R. E. 2016. Spinal Manipulation verse Sham Manipulation for Non-specific Low Back Pain: A Systematic Review and Meta-analysis*. Journal of Chiropractic Medicine*, 15: 165-183.

Sabick, M. B., Torry, M. R., Lawton, R. L. and Hawkins, R. J. 2004. Valgus torque in youth baseball pitchers: A biomechanical study. *J Shoulder Elbow Surg*, 13(3): 349-355.

Schwartzbauer, J. 2013. Athletic Performance and Physiological Measures in Baseball Players Following Upper Cervical Chiropractic Care: A pilot study. Annals of Vertebral Subluxation Research. *Spine Journal*, 1 (4): 1-7.

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C. A., Nicholson, G. P. and Romeo, A. A. 2010. The Kinetic Chain in Overhand Pitching: Its Potential Role for Performance Enhancement and Injury Prevention. *Sports Health*, 2(2): 135-146.

Sharrock, C., Cropper, J., Mostad, J., Johnson, M. and Malone, T. 2011. A pilot study of core stability and athletic performance: is there a relationship? *International Journal of Sports Physical Therapy.*, 6 (2): 63-74.

Sood, K. D. 2008. The immediate effect of lumbar spine manipulation, thoracic spine manipulation, combination lumbar and thoracic spine manipulation and sham laser on bowling speed in action cricket fast bowlers, Master's Degree in Chiropractic, Durban University of Technology.

Spine, M. 2017. *Spinal anatomy* (online). Virginia Spine Institute. Available: https://www.spinemd.com/symptoms-conditions/spine-anatomy (Accessed 1 September 2018).

Stodden, D. F., Fleisig, G. S., McLean, S. P. and Andrews, J. R. 2005. Relationship of biomechanical factors to baseball pitching velocity: within particular variation. *Journal of Applied Biomechanics*, 21: 44 - 56.

Stodden, D. F., Fleisig, G. S., Mclean, S. P., Lyman, S. L. and Andrews, J. R. 2001. Relationship of trunk kinematics to pitched ball velocity. *Journal of Applied Biomechanics*, 17: 164-172.

Stuelcken, M. C., Ginn, K. A., Sinclair, P. J. 2008. Shoulder strength and range of motion in elite female cricket fast bowlers with or without history of shoulder pain. Journal of Science Medicine Sport, 11 (6): 575-580

Stretch, R. A. and Venter, D. J. L. 2005. Cricket injuries - a longitudinal study of the nature of injuries to South African cricketers: original research article. *South African Journal of Sports Medicine*, 17(3): 4-10.

Sullivan, M. S., Dickinson, C. E. and Troup, J. D. 1994. The influence of age and gender on lumbar spine sagittal plane range of motion. A study of 1126 healthy participants. *Spine* (Phila Pa 1976), 19(6): 682-686.

Summer, M. 2015. Biomechanics Analysis (Cricket Fast Bowling). *What are the biomechanical principles required for cricket fast bowler's* (Blog). Available:http://milessumner.blogspot.com/2015/06/biomechanics-analysis-cricket-fast.html (Accessed 23 July 2018).

Trella, C. 2012. A 3-year investigation into the incidence and nature of cricket injuries in elite South African schoolboy cricketers. *South African Sports Medicine Association*, 24. Available: DOI: https://doi.org/10.17159/2078-516X/2012/v24i1a360.

Triano, J. J., Rogers, C. M., Combs, S., Potts, D. a. and Sorrels, K. 2003. Quantitative feedback versus standard training for cervical and thoracic manipulation. *Journal of Manipulative and Physiological Therapeutics*, 26 (3): 131-138.

Umezu, Y., Kawazu, T., Tajima, F. and Ogata, H. 1998. Spectral electromyographic fatigue analysis of back muscles in healthy adult women compared with men. *Arch Phys Med Rehabil*, 7(5): 536-538.

Van Herp, G., Rowe, P., Salter, P. and Paul, J. P. 2000. Three-dimensional lumbar spinal kinematics: a study of range of movement in 100 healthy participants aged 20 to 60+ years. *Rheumatology*, 39(12): 1337-1340.

Wallis, R., Elliot, B. C., Koh, M. 2002. The effect of fast bowling harness in cricket: an intervention study. *Journal of Sports Sciences*, 20 (6): 495-506.

Weber, A. E., Kontaxis, A., O'Brien, S. J. and Bedi, A. 2014. The biomechanics of throwing: simplified and cogent. *Journal of Sports Medicine*, 22 (2): 72-79.

Wiggett, M. 2015. The immediate effect of spinal manipulative therapy on drag flicking performance of field hockey players. Masters in Chiropractic, Durban University of Technology.

Willard, F. H., Vleeming, A., Schuenke, M. D., Danneels, L and Schleip, R. 2012. Thoracolumbar fascia; anatomy, function, clinical considerations. *Journal of Anatomy*, 221 (6): 507-536.

Wirth, B., Gassner, A., de Bruin, E. D., Axen, I., Swanenburg, J., Humphreys, B. K., Schweinhardt, P. (2019). Neurophysiological effects of high velocity and low amplitude spinal manipulation in symptomatic and asymptomatic humans: A systemic literature review. *Spinal Journal*, 44 (15): 926.

Werner, S. L., Suri, M., Guido, J. A., Meister, K. and Jones, D. G. 2008. Relationship between ball velocity and throwing mechanics in collegiate baseball pitchers. *Journal of Shoulder Elbow Surgery*, 17(6): 905-908.

Williams, B. 2017. Normal human range of motion. Available: https;//www.livestrong.com/article/257162-normal-human-range-of-motion/

Worthington, P. J. 2010. *A biomechanical analysis of fast bowling in cricket*. Docrat, Loughborough University.

Worthington, P. J., King, M. A. and Ranson, C. A. 2013. Relationships between fast bowling technique and ball release speed in cricket. *Journal of Applied Biomechanics*, 29: 74-84.

Yang, S. R., Kim, K. and Park, S. J. 2015. The effect of thoracic spine mobilization and stabilization exercise on the muscular strength and flexibility of the trunk of chronic low back pain patients. *Journal of Physical Therapy Science*, 27 (12): 3851-3854.

Yezak, M. 2018. Thoracic spine anatomy and upper back pain 04/03/2018. Available: https://www.spine-health.com/conditions/spine-anatomy/thoracic-spine-anatomy-and-upper-back-pain (Accessed 31/07/2018).

Young, J. L., Herring, S. A., Press, J. M. and Casazza, B. A. 1996. The influence of the spine on the shoulder in the throwing athlete. *J Back Musculoskeletal Rehabilitation*, 7 (1): 5-17.

Zheng, N. N., Barrentine, S. W., Fleisig, G. S. and Andrews, J. R. 2008a. Swing kinematics for Male and Female Pro Golfers. International Journal of Sports Medicine, 29(12): 965 – 970.

Zheng, N. N., Barrentine, S. W., Fleisig, G. S. and Andrews, J. R. 2008b. Swing kinematics for Male and Female Pro Golfers*. International Journal of Sports Medicine*, 29(12): 965-970.

APPENDICES

APPENDIX A: Advertisement

ATTENTION ALL CRICKETERS

ARE YOU HEALTHY AND
BETWEEN THE AGES OF
18 AND 40 YEARS?

HAVE YOUR BOWLING SPEED MEASURED!

RESEARCH IS BEING CONDUCTED IN LOCAL CRICKET ARENAS ON 3 INTERVENTIONS THAT MAY AFFECT YOUR BOWLING SPEED

IF YOU ARE INTERESTED IN PARTICIPATING IN THIS FREE RESEARCH STUDY, PLEASE CONTACT:

PRASANTHI – 082 7255 803

APPENDIX B: Letter of Information

DUT DURBAN UNIVERSITY OF TECHNOLOGY — INSTITUTIONAL RESEARCH ETHICS COMMITTEE

Title of the Research Study:

The immediate effect of lumbar spine manipulation, thoracic spine manipulation and placebo manipulation on range of motion and bowling speed in asymptomatic male and female indoor cricket bowlers.

Principal Investigator/s/researcher:

Prasanthi Nayager B. Tech Chiropractic

Co-Investigator/s/supervisor/s:

Supervisor: Dr Praveena Maharaj, M. Tech Chiropractic

Co-Supervisor: Dr Kanwal Sood, M. Tech Chiropractic

Brief Introduction and Purpose of the Study:

This study involves assessing range of motion and bowling speed in asymptomatic elite male and female cricket bowlers. This study is being conducted to assess whether spinal manipulation may cause a change in an individual's range of motion and bowling speed.

Outline of the Procedures:

A full case history, physical examination and orthopedic examination of the spine will be completed in an enclosed area. After this you will be allocated to one of three intervention groups depending on the piece of numbered paper you pick from the hat i.e. Group 1 (thoracic spine manipulation), Group 2 (lumbar spine manipulation) and, Group 3 placebo manipulation. You will then need to do a five-minute warm up to stretch your muscles. Your back's range of motion will be measured using a digital inclinometer. You will then be asked to bowl, and the speed will be measured by a radar gun. Depending on the group you were allocated, the appropriate intervention will then be applied. Your back's range of motion will be measured again as previously, and you will then be asked to bowl again, and the bowling speed will be measured. Thereafter, you will be asked to answer a mini questionnaire on your indication of the change in bowling speed before and after the intervention. The consultation is expected to last about one and a half hours. You will be required to attend a one-hour consultation at the D.U.T Chiropractic Clinic followed by a 30-minute consultation at Sahara Stadium Kingsmead Cricket or Chatsworth Oval. You will be required to perform the instructed warm up and bowling procedures and to comply with the range of motion tests.

Risks or Discomforts to the Participant:

All consultations are supervised by a registered, qualified chiropractor. You may feel slight temporary discomfort during the spinal manipulation. There is no other discomfort expected with this intervention.

Benefits:
The results of the study will be forwarded to the school and club coaches to allow for improvements in training to be made.

Reason/s why the Participant May Be Withdrawn from the Study:
Non-compliance, illness, adverse reactions, etc. these participants may be removed, however there are no repercussions. Should you wish to withdraw from this study at any time you may do so without explanation and your information will not be used for this study.

Remuneration:
Each participant will receive a cricket ball.

Costs of the Study:
Participation is voluntary and at no cost.

Confidentiality:
All your information is confidential, and the results of the study will be used for research purposes only. The researcher will be the only person who has access to the letters of consent and after the data collection process the data will be coded. You are entitled to be informed of any findings that are made from the study, and you are free to ask questions of an independent source. If you feel unsatisfied with any area of the study, please contact the Durban University of Technology Research Ethics Committee. The information will be stored in the Department of Chiropractic and after a minimum of 5 years it will be disposed of via shredding.

Research-related Injury:
Indemnity cover relating to research activities is covered by the Durban University of Technology.

Persons to Contact in the Event of Any Problems or Queries:

Researcher - Prasanthi Nayager	Cell number: 082 725 5803
Supervisor – Dr Praveena Maharaj	Cell number: 073 256 7399
Co-Supervisor – Dr Kanwal Sood	Cell number: 083 556 7949

Institutional Research Ethics Administrator: Telephone number: 031 373 2375

Complaints can be reported to the Director: Research and Postgraduate Support,

Prof S Moyo Phone: 031 373 2577 or

Email: moyos@dut.ac.za

General:
Potential participants must be assured that participation is voluntary and the approximate number of participants to be included should be disclosed. A copy of the information letter should be issued to participants. The information letter and consent form must be translated and provided in the primary spoken language of the research population e.g. isiZulu.

APPENDIX C: Informed Consent

CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Prasanthi Nayager, about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: _____,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerized system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had enough 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 this research which may relate to my participation will be made available to me.

______________________	______________	____________
Full Name of Participant	**Date**	**Time**

____

Signature/Right Thumbprint

I, Prasanthi Nayager herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

______________________	______________	____________
Full Name of Researcher	**Date**	**Signature**
______________________	______________	____________
Full Name of Witness (If applicable)	**Date**	**Signature**
______________________	______________	____________
Full Name of Legal Guardian (If applicable)	**Date**	**Signature**

APPENDIX D: Case History

DUT DURBAN UNIVERSITY OF TECHNOLOGY — DEPARTMENT OF CHIROPRACTIC

CHIROPRACTIC DAY CLINIC
CASE HISTORY

Patient: ______________________________ Date: __________

File #: __________ Age: __________

Gender: __________ Occupation: ______________________

Student: ______________________ Signature ______________

FOR CLINICIANS USE ONLY:

Initial visit

Clinician: Signature:

Case History:

Examination:
Previous: Current:

X-Ray Studies:
Previous: Current:

Clinical Path. lab:
Previous: Current:

CASE STATUS:

PTT:	Signature:	Date:

CONDITIONAL: Reason for Conditional:	
Signature:	Date:

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

Case Summary signed off:	Date:

Student's Case History:

Page 1 of 4

1. **Source of History:**

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

3. **Present Illness:**

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

4. **Other Complaints:**

5. **Past Medical History:**

General Health Status

Childhood Illnesses

Adult Illnesses

Psychiatric Illnesses

Accidents/Injuries

Surgery

Hospitalizations

6. Current health status and life-style:

Allergies

Immunizations

Screening Tests incl. x-rays

Environmental Hazards (Home, School, Work)

Exercise and Leisure

Sleep Patterns

Diet

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

Tobacco
Alcohol
Social Drugs

7. Immediate Family Medical History:

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

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

8. Psychosocial history:

Home Situation and daily life
Important experiences
Religious Beliefs

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

General

Skin

Head

Eyes

Ears

Nose/Sinuses

Mouth/Throat

Neck

Breasts

Respiratory

Cardiac

Gastro-intestinal

Urinary

Genital

Vascular

Musculoskeletal

Neurologic

Haematological

Endocrine

Psychiatric

APPENDIX E: Physical Examination

DUT DURBAN UNIVERSITY OF TECHNOLOGY | DEPARTMENT OF CHIROPRACTIC

PHYSICAL EXAMINATION: SENIOR

Patient Name: ______________________ **File no:** __________ **Date:** __________

Student: **Signature:**

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

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

SYSTEM SPECIFIC EXAMINATION:

CARDIOVASCULAR EXAMINATION

RESPIRATORY EXAMINATION

ABDOMINAL EXAMINATION

NEUROLOGICAL EXAMINATION

COMMENTS

Clinician: **Signature:**

Page 1

APPENDIX F: Lumbar Regional

DUT DURBAN UNIVERSITY OF TECHNOLOGY DEPARTMENT OF CHIROPRACTIC

REGIONAL EXAMINATION
LUMBAR SPINE AND PELVIS

Patient:______________________ File#:__________ Date:________

Student:______________________ Clinician:____________________

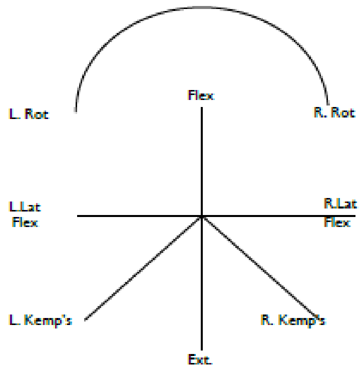
STANDING:

Posture– scoliosis, antalgia, kyphosis
Body Type
Skin
Scars
Discolouration

Minor's Sign
Muscle tone
Spinous Percussion
Schober's Test (6cm)
Bony and Soft Tissue Contours

GAIT:

Normal walking
Toe walking
Heel Walking
Half squat



ROM:

Forward Flexion = 40-60° (15 cm from floor)
Extension = 20-35°
L/R Rotation = 3-18°
L/R Lateral Flexion = 15-20°

Which movement reproduces the pain or is the worst?

- Location of pain
- Supported Adams: Relief? (SI)
- Aggravates? (disc, muscle strain)

SUPINE:

Observe abdomen (hair, skin, nails)
Palpate abdomen\groin
Pulses - abdominal
- lower extremity

Abdominal reflexes

		Degree	LBP?	Location	Leg pain	Buttock	Thigh	Calf	Heel	Foot	Braggard
SLR	**L**										
	R										

	L	**R**
Bowstring		
Sciatic notch		
Circumference (thigh and calf)		
Leg length: actual -		
apparent -		
Patrick FABERE: pos\neg – location of pain?		
Gaenslen's Test		
Gluteus max stretch		
Piriformis test (hypertonicity?)		
Thomas test: hip \ psoas \ rectus femoris ?		
Psoas Test		

SITTING:

Spinous Percussion
Lhermitte

Valsalva

Page 1 of

TRIPOD SI, +, ++		Degree	LBP?	Location	Leg pain	Buttock	Thigh	Calf	Heel	Foot	Braggard
	L										
	R										

SLUMP 7 TEST	L										
	R										

LATERAL RECUMBENT:	L	R
Ober's		
Femoral n. stretch		
SI Compression		

PRONE:	L	R
Gluteal skyline		
Skin rolling		
Iliac crest compression		
Facet joint challenge		
SI tenderness		
SI compression		
Erichson's		
Pheasant's		

MF tp's	Latent	Active	Radiation
QL			
Paraspinal			
Glut Max			
Glut Med			
Glut Min			
Piriformis			
Hamstring			
TFL			
Iliopsoas			
Rectus Abdominis			
Ext/Int Oblique muscles			

NON ORGANIC SIGNS:

Pin point pain
Trunk rotation
Flip Test
Ankle dorsiflexion test

Axial compression
Burn's Bench test
Hoover's test
Repeat Pin point test

NEUROLOGICAL EXAMINATION

Fasciculations						
Plantar reflex						
level	**Tender?**	**Dermatomes**		**DTR**		
		L	**R**		**L**	**R**
T12				Patellar		
L1				Achilles		
L2						
L3				Proprioception		
L4						
L5						
S1						
S2						
S3						

MYOTOMES

Action	**Muscles**	**Levels**	**L**	**R**	
Lateral Flexion spine	Muscle QL				
Hip flexion	Psoas, Rectus femoris				5+ Full strength
Hip extension	Hamstring, glutes				4+ Weakness
Hip internal rotation	Glutmed, min, TFL, adductors				3+ Weak against grav
Hip external rotation	Gluteus max, Piriformis				2+ Weak w\o gravity
Hip abduction	TFL, Glut med and minimus				1+ Fascic w\o gross movt
Hip adduction	Adductors				0 No movement
Knee flexion	Hamstring,				
Knee extension	Quad				W - wasting
Ankle plantarflexion	Gastrocnemius, soleus				
Ankle dorsiflexion					
Inversion					
Eversion					
Great toe extensor					

MOTION PALPATION AND JOINT PLAY	**L**	**R**
Lumbar Spine		
Sacroiliac Joint		

Page 3 of

APPENDIX G: Thoracic Regional

DUT DURBAN UNIVERSITY OF TECHNOLOGY — DEPARTMENT OF CHIROPRACTIC

THORACIC SPINE
REGIONAL EXAMINATION

Patient:______________________________ File:__________ Date:____________________

Student:______________________________ Signature:______________________________

Clinician:_____________________________ Signature:______________________________

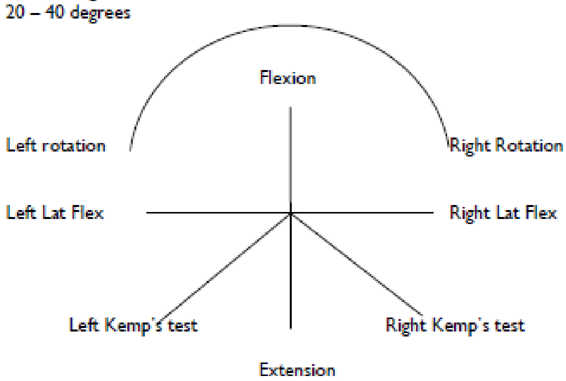
STANDING:

Posture (incl. L/S & C/S)
Muscle tone
Skyline view – Scoliosis
Spinous Percussion
Breathing (quality, rate, rhythm, effort)
Deep Inspiration

Scars
Chest deformity
(pigeon, funnel, barrel)

RANGE OF MOTION:

Forward Flexion	20 – 45 degrees (15cm from floor)
Extention	25 – 45 degrees
L/R Rotation	35 – 50 degrees
L/R Lat Flex	20 – 40 degrees



RESISTED ISOMETRIC MOVEMENTS: (in neutral)

Forward Flexion
L/R Rotation

Extension
L/R Lateral Flexion

SEATED:

Palpate Auxillary Lymph Nodes
Palpate Ant/Post Chest Wall
Costo vertebral Expansion (3 – 7cm diff. at 4th intercostal space)
Slump Test (Dural Stretch Test): LOCAL PAIN (T/S) DISTAL PAIN (L/S) DISTAL PAIN (LEG)

SUPINE:

Rib Motion (Costo Chondral joints)
Soto Hall Test (#, Sprains)

SLR
Palpate abdomen

PRONE:

Passive Scapular Approximation
Facet Joint Challenge
Vertebral Pressure (P-A central unilateral, transverse)
Active myofascial trigger points:

	Latent	Active	Radiation Pattern		Latent	Active	Radiation Pattern
Rhomboid Major				Rhomboid Minor			
Lower Trapezius				Spinalis Thoracic			
Serratus Posterior				Serratus Superior			
Pectoralis Major				Pectoralis Minor			
Quadratus Lumborum							

COMMENTS:____

NEUROLOGICAL EXAMINATION:

DERMATOMES												
	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	T 11	T 12
Left												
Right												

Basic LOWER LIMB neuro:

Myotomes	T11	T12	L1	L2	L3	L4	L5	S1	S2	S3
Dermatomes	T11	T12	L1	L2	L3	L4	L5	S1	S2	S3
Reflexes	Patella – Left					Achilles – Left				
	Patella - Right					Achilles – Right				

MOTION PALPATION:

			Right	Left
Thoracic Spine				
Ribs	Calliper (Costo-transverse joints)			
	Bucket Handle	Opening		
		Closing		

APPENDIX H: Permission for use of Chatsworth Oval

Good day Sir/Madam

My name is Prasanthi Nayager and I am currently completing my Master's in Chiropractic. To obtain a Master's in Chiropractic one needs to complete a research project. The title of my research project is: **The immediate effect of lumbar spine manipulation, thoracic spine manipulation and placebo manipulation on range of motion and bowling speed in asymptomatic male and female indoor cricket bowlers**.

In order for me to complete my data collection, I would need to make use off your cricket venue for the period of my data collection.

I would appreciate if you could grant me permission to do so.

I hope to hear from you soon.

Kind regards

Ms. P. Nayager

……………………….

APPENDIX I: Permission for use of Sahara Stadium Kingsmead

KWAZULU-NATAL CRICKET

KwaZulu Natal Cricket Union
P.O. Box 47266, Greyville, 4023,
Kingsmead Stadium

2 Kingsmead Way,
off Masabalala Yengwa Avenue,
Durban 4001

Telephone: 031 335 4200
Fax: 031 332 5288
Playing Affairs Fax: 031 335 5288
Email: dolphins@cricket.co.za

VAT No: 4760101461

13 December 2018

TO WHOM IT MAY CONCERN

Re: Permission - Kingsmead Stadium Indoor

Dear Sir/Madam,

This letter confirms that provisional permission has been granted to Ms. P. Nayager for the usage of Kingsmead Stadium Indoor Facility.

Please note that the facility is available from 08:00 to 14:00 daily. The days and times will vary depending on its availability, also note that facility will be unavailable when the KZN Cricket Union or Cricket South Africa is hosting Provincial or International matches.

Should you have any queries please do not hesitate to contact me.

Regards,

Ritesh Ramjee
Cricket Services Manager: KZN Coastal
Kwazulu Natal Cricket Union

APPENDIX J: Off-site Supervisor Permission

KWAZULU-NATAL CRICKET

KwaZulu Natal Cricket Union
P.O. Box 47266, Greyville, 4023,
Kingsmead Stadium

2 Kingsmead Way,
off Masabalala Yengwa Avenue,
Durban 4001

Telephone: 031 335 4200
Fax: 031 332 5288
Playing Affairs Fax: 031 335 5288
Email: dolphins@cricket.co.za
VAT No: 4760101461

20 November 2018

Dear Sir/Madam

RE – PRASANTHI NAYAGER

This letter serves to confirm that Prasanthi Nayager will be allowed to use the Chatsworth Cricket Oval facility for her data collection for the period required.

We wish her well in her studies and should you require any further information please do not hesitate to contact me.

Yours faithfully

J Sathiaseelan
Cricket Services Manager

APPENDIX K: IREC Approval

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

P O Box 1334, Durban, South Africa, 4001

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

www.dut.ac.za

11January 2019

Ms P Nayager
76 Beatrice Street
Durban
4001

Dear Ms Nayager

The immediate effect of lumbar spine manipulation, thoracic spine manipulation and placebo manipulation on range of motion and bowling speed in asymptomatic male and female indoor cricket bowlers

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

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

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

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

Yours Sincerely,

Professor J K Adam
Chairperson: IREC

APPENDIX L: Mini Questionnaire

PARTICIPANTS' PERCEPTION TO CHANGE IN BOWLING SPEED

Group 1a	Increased	Decreased	No Change	Group 1b	increased	Decreased	No change
1.				1.			
2.				2.			
3.				3			
4.				4.			
5.				5.			
6.				6.			
7.				7.			
8.				8.			
9.				9.			
10.				10.			

Group 2a	Increased	Decreased	No Change	Group 2b	Increased	Decreased	No Change
1.				1.			
2.				2.			
3.				3.			
4.				4.			
5.				5.			
6.				6.			
7.				7.			
8.				8.			
9.				9.			
10.				10.			

Group 3a	Increased	Decreased	No Change	Group 3b	Increased	Decreased	No Change
1.				1.			
2.				2.			
3.				3.			
4.				4.			
5.				5.			
6.				6.			
7.				7.			
8.				8.			
9.				9.			
10.				10.			

Mini Questionnaire

1. Do you feel there is a change in your bowling speed? Yes/No
2. Has your bowling speed increased, decreased or remained the same? Yes/No
3. Can your information and results be used in the study? Yes/No

APPENDIX M: Bowling Speed Data Collection Form

BOWLING SPEED DATA COLLECTION

Group 1a	Speed (km/h)		Group 1b	Speed (km/h)
1.			1	
2.			2.	
3.			3.	
4.			4.	
5.			5.	
6.			6.	
7.			7.	
8.			8.	
9.			9.	
10.			10.	

Group 2a	Speed (km/h)		Group 2b	Speed (km/h)
1.			1	
2.			2.	
3.			3.	
4.			4.	
5.			5.	
6.			6.	
7.			7.	
8.			8.	
9.			9.	
10.			10.	

Group 3a	Speed (km/h)		Group 3b	Speed (km/h)
1.			1	
2.			2.	
3.			3.	
4.			4.	
5.			5.	
6.			6.	
7.			7.	
8.			8.	
9.			9.	
10.			10.	

APPENDIX N: Range of Motion Data Collection Form

Participant	T/S FF	Post	T/S Ext	Post	T/S RLF	Post	T/S LLF	Post	T/S RPA	Post	T/S LPA	Post
Males												
1.												
2.												
3.												
4.												
5.												
6.												
7.												
8.												
9.												
10.												
11.												
12.												
13.												
14.												
15.												
16.												
17.												
18.												
19												
20.												
21.												
22.												
23.												
24.												
25.												
26.												
27												
28.												
29.												
30.												
Females												
31.												
32.												
33.												
34.												
35.												
36.												
37.												
38.												
39.												
40.												
41.												
42.												
43.												
44.												
45.												
46.												
47.												
48.												
49.												
50.												
51.												
52.												
53.												
54.												
55.												
56.												
57.												
58.												
59.												
60												