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Lower Quarter Muscle Activation in Adolescent Tennis Players with and without Lower Back Pain

Elandie Elizabeth Immelman - 1584887



A dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, in fulfilment of the requirements for the Degree MSc (Physiotherapy), Gauteng, 2018.

DECLARATION

I, Elandie Elizabeth Immelman, declare that the work contained in this dissertation is my own work, except to the extent indicated in the acknowledgement sections.

This dissertation is being submitted for the Degree of MSc (Physiotherapy), at the University of the Witwatersrand, Johannesburg, South Africa.

This work has not been submitted for any other degree or examination at this or any other university.

_____ 06/06/2019_____

Elandie Elizabeth Immelman Date

ABSTRACT

Background

Injury can cause long periods away from active training and if not addressed correctly may lead to recurrent injuries or chronic pain. Approximately 20% of adolescent tennis players suffer from lower back pain. Extrinsic and intrinsic risk factors could contribute to injury in tennis players. The most powerful and strenuous stroke in tennis is the serve. Motor control is crucial during a force-generating stroke such as the tennis serve. Motor control is the result of a harmonious co-activation relationship between muscle groups. The aims of this study were to compare the muscle activation and joint angles of the lower quarter during the different phases of the tennis serve in adolescent tennis players with and without lower back pain. Further aims of this study compared the demographics, active Range Of Motion (ROM) of the lumbar spine and hips, the Star Excursion Balance Test (SEBT) and the relationship between variables in adolescent tennis players with and without lower back pain. Identifying risk factors in the chosen variables could equip the player with an individualised, well-balanced training programme in order to prevent or to rehabilitate an injury.

Study Design

This study used a cross-sectional, observational design.

Method

A total of 138 junior tennis players, between the ages of 10 and 18, and who were members of the North Gauteng Tennis Club in 2017, were selected for this research study. Junior tennis players were invited, with no prejudice or pressure, to participate in the study which

more specifically included adolescent tennis players who played tennis at least once a week and who had played tennis for at least three years prior to this study. Tennis players were excluded from participating in the study if they had been diagnosed with any acute musculoskeletal injuries, metabolic conditions, spinal fractures, spinal pathology, or had undergone any spinal surgery.

Participants completed a self-report questionnaire regarding their demographic history. Physical testing included active ROM and the SEBT. Further physical testing incorporated motion analysis (Inertial Measurement Unit system) and wireless surface electromyography (EMG) during the tennis serve. A total of six service motions were recorded and used for analysis. Seven markers, to detect different phases of the serve, were identified during data processing. The phases were used to analyse the kinematics and muscle activation during the tennis serve at that point. Kinematic analyses of the trunk and bilateral hips were conducted. The rectus abdominis (RA), external obliques (EO), erector spinae (ES) and gluteus maximus (GM) muscles were evaluated during the tennis serve.

Lower back pain status was used as the dependent variable. Means and standard deviations were used to describe the demographic history and point of maximum muscle activity. Medians and ranges were used to present active ROM, SEBT, kinematics and muscle activation. The Chi-Square (X^2) test was used to look at the differences between the categorical variables, while a Mann-Whitney U test was used to determine the significant differences between the independent variables. A Pearson bivariate correlation analysis was performed to determine the relationships between the significant variables. Furthermore, a binary logistic regression model determined which of the variables found in

the correlation was the strongest at predicting whether a participant would be categorised into the Lower Back Pain (LBP) or No Lower Back Pain (NLBP) groups. The Forward Stepwise (Wald) method was used.

Results

A total of 33 adolescent tennis players from the North Gauteng Tennis Club participated in this study. The sample comprised of 21 participants without lower back pain (the NLBP group: 13.43 ± 2.20 years old) and 12 participants with lower back pain (the LBP group: 14.92 ± 1.98 years old).

A significant association was found between lower limb dominance (p=0.015), where the LBP group consisted of significantly more left lower limb dominant tennis players (NLBP two left; 19 right; LBP five left; seven right). There was a significant association between the number of hours played on a hard-court surface and the presence of LBP (p=0.052). All participants reported playing on a hard court and spent an average of 5.86±2.59hrs (NLBP group) and 8.08±3.73hrs (LBP group), per week. Furthermore, compared to the LBP group, the NLBP group spent significantly more time playing other types of sport per week (p=0.045; NLBP 3.48±2.89hrs; LBP 1.42±2.39hrs).

The only significant difference found during the active ROM testing was for lumbar lateral flexion to the right. The NLBP group had a significantly greater median range of 36° for right-sided lateral flexion (p=0.012) compared to the 29° for the LBP group. Results from the SEBT indicated differences in the left anteromedial (p=0.011), left anterior (p=0.047), right

anterolateral (p=0.010), left posterolateral (p=0.047) and right posterior (p=0.041) reach directions.

Differences in joint angles and muscle activation between the two groups were seen in all phases of the tennis serve. The most important findings were in the start point of the preparation phase (PS), the ball release point of the preparation phase (PR), the loading point of the preparation phase (PL) and the finish point of the deceleration phase (DF). Generally, compared to the LBP group, the NLBP group experienced greater muscle activation in the RA and EO muscles during the preparation and acceleration phases. Furthermore, the ES and GM were more active during the preparation phase for the NLBP group. However, the ES was more active in the LBP group for most of the phases (PL to DF). During the end phase of the serve (DF), the LBP group experienced greater activation in the anterior and posterior trunk musculature.

The analysis of the kinematics and muscle activation during the tennis serve ascertained the following:

(1) The LBP group displayed different levels of muscle activation and different reactions in the kinematic mechanisms in the hips and trunk (i.e. it is proposed that the LBP group used rotatory mechanisms whilst the NLBP group made use of vertical linear mechanisms);

(2) The recruitment of motor units was slower in the LBP group;

(3) The movement patterns of the trunk and hips in the LBP group were mal-adaptive in terms of shock absorption.

The logistic regression displayed three key points that could assist in the identification of risk factors for LBP during the tennis serve.

- Firstly, a smaller angle of hip flexion (PS OR=0.75; PR OR=0.62) and external rotation (PR OR=1.406; PL OR=0.866) during the preparation phase;
- Secondly, a greater degree of adduction (DF OR=0.533), internal rotation (DF OR=1.252) and flexion (DF OR=1.269) of the hip during the deceleration phase. [These kinematics key points emphasise the importance of force transfer over a stable base of support.];
- Thirdly, the importance of correct muscle activation (concentric and eccentric) of the anterior trunk and control throughout movement during the loading (RA OR=0.645; EO OR=1.101) and deceleration (RA OR=1.537) phases. [The muscle-activity key point emphasises the importance of muscle strength and the global stability functional testing.]

Conclusion

The results present valuable intrinsic and extrinsic risk factors that could contribute to injury in adolescent tennis players. The focus in this study was on kinematics and muscle activation during the serve. An evaluation of the tennis serve showed that the two groups displayed different preparation and execution strategies regarding the kinematics and muscle recruitment needed to move between the phases. The NLBP group made use of more hip flexion during the serve. In contrast, the LBP group relied more on trunk rotation and lateral flexion during the serve. This can be explained as a vertical linear mechanism

versus a rotatory mechanism for force generation and transfer. The NLBP group displayed greater muscle activation in the preparation and acceleration phases.

The findings support the theory of pain adaptations and pain inhibition in players with lower back pain. We can conclude that the LBP group made use of a compensatory mechanism in order to adapt to their pain and/or restriction of movement and therefore displayed a lack of motor control.

One of the major strengths of this study is that the identification of variables that have an effect on lower back pain status could play an important role in the prevention of injury and in rehabilitation programmes. The three key points need to be kept in mind in the treatment and training of adolescent tennis players. These findings can be used in motor-control re-training and in other rehabilitation programmes. Furthermore, this could impact on the high incidence of lower back pain and chronic pain in the future.

Keywords

Tennis, adolescent, serve, lower back pain, lower quarter, kinematics, muscle activation, risk factors, motor control, kinetic control.

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LIST OF ABBREVIATIONS

%MAXD
Maximised reach distance in percentage 46
AC1
Acceleration Phase: Ball Contact 60
AC2
Acceleration Phase: Maximum Shoulder Abduction 60
APP
Application 42
ASIS
Anterio Superior Iliac Spine 46
BMI
Body Mass Index 68
DF
Deceleration Phase: Final 60
EMG
Electromyography 30
EO
External Oblique muscle 23
ES
Erector Spinae muscle 23
fEMG
Fine-wire Electromyography 50
GM
Gluteus Maximus muscle 23
IMU
Inertial Measurement Unit 35
LA REACH
Left weight-bearing with anterior reach 75
LAL REACH
Left weight-bearing with antero-lateral reach 75
LAM REACH
Left weight-bearing with antero-medial reach 75
LBP
Lower Back Pain 39
LL REACH
Left weight-bearing with lateral reach 75
LP REACH
Left weight-bearing with posterior reach 75
LPL REACH
Left weight-bearing with postero-lateral reach 75
LPM REACH
Left weight-bearing with postero-medial reach 75
MRI
Magnetic Resonance Imaging 12
MVIC
Maximum Voluntary Isometric Contraction 36
NLBP
No Lower Back Pain 40
PC
Preparation Phase: Cocking 60
PL

Preparation Phase: Loading 60
PR
Preparation Phase: Ball Release 60
PS
Preparation Phase: Start 60
RA
Rectus Abdominis muscle 23
RA REACH
Right weight-bearing with anterior reach 75
RAL REACH
Right weight-bearing with antero-lateral reach 75
RAM REACH
Right weight-bearing with antero-medial reach 75
RL REACH
Right weight-bearing with lateral reach 75
ROM
Range Of Motion 4
RP REACH
Right weight-bearing with posterior reach 75
RPL REACH
Right weight-bearing with postero-lateral reach 75
RPM REACH
Right weight-bearing with postero-medial reach 75
SEBT
Star Excursion Balance Test 32
sEMG
Surface Electromyography 49
SENIAM
Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles 51
USA
United States of America 1
VAS
Visual Analogue Scale 67

CHAPTER 1: INTRODUCTION

1.1 Background and Need

To succeed, one needs to master the art of one's sport. That is why we say "practice makes perfect". Many elite adolescent tennis players aim to make their sport a profession in the future. These tennis players are passionate and dedicated. They spend hours in order to perfect their sporting technique. Often this leads to overtraining and/or recurrent injuries on account of a lack of proper technique and rest. In a study done in the United States of America (USA), it was found that back pain is the most common site of injury in adolescent male tennis players (Abrams, Renstrom and Safran, 2012). Injury can cause long periods away from active training and if not addressed correctly, may lead to recurrent injuries or chronic pain.

Common risk factors for back pain in adolescent tennis players include, but is not limited to, previous injury to the back and the playing of tennis for more than six hours per week (Hjelm, Werner and Renstrom, 2012). Exposure to tennis is a risk factor for injury to the back (Hjelm, Werner and Renstrom, 2012), but it can also be a preventative measure against injury with health promotion benefits (Ahlqwist *et al.*, 2008; Malliou, 2015). How to identify the line between health promotion and performance in sport whilst preventing the risk factors for a chronic recurrent injury has become vital. Identifying muscle activity and kinematics could assist in guiding the player to employ proper technique during play and could ultimately be a preventative measure.

The most powerful and strenuous stroke in tennis is the serve (Kibler and Safran, 2005; Abrams, Renstrom and Safran, 2012; Hjelm, Werner and Renstrom, 2012). Fifty-four percent (54%) of the total force in a serve is developed in the lower quarter (Johnson and McHugh, 2006; Abrams, Renstrom and Safran, 2012). The trunk forms an integral part of the transmission sequence (Correia *et al.*, 2016). The force generated needs to transfer from the lower quarter, through the trunk, towards the upper quarter in order to propel the ball forward in a powerful stroke. However, adolescent tennis players often have weak lower extremity muscle strength (Hjelm, Werner and Renstrom, 2012), and changes in the timing and sequence of muscle activity and kinematics during the serve could be risk factors for back pain.

Motor control is crucial during a force-generating stroke such as the tennis serve. Motor control is the result of a harmonious co-active relationship between muscle groups. During the serve, the co-activation of the lower trunk muscles assists in the stabilisation of the lumbar spine during extension/flexion and rotation (Chow, Shim and Lim, 2003; Elliott, 2006). Chronic lower back pain patients have a lack of feed-forward activation in the core musculature, which leads to motor control dysfunction (Ganesh, Chhabra and Mrityunjay, 2015). Lumbar kinematics during the tennis serve has been shown to alter for tennis players with lower back pain. Campbell *et al.* (2013) found that tennis players with lower back pain use significantly greater lateral flexion force during the acceleration phase of both the kick and flat serves. This suggests that adolescent tennis players with lower back pain could exhibit changes in their lower quarter muscle activation and kinematics. Therefore, the need to look more closely at muscle activation and kinematics during the tennis serve was identified.

1.2 Problem Statement

Lower back pain among adolescents is a risk factor for lower back pain in adulthood (Andersen, Wedderkopp and Leboeuf-Yde, 2006; Ahlqwist *et al.*, 2008; Fontecha *et al.*, 2011). Sadly, many professional tennis players retire on account of chronic lower back pain (Kibler and Safran, 2005). Undisputedly, the fact remains that lower back pain is one of the most debilitating diseases of our time and that it occurs with an ever-increasing frequency. Lower back pain has been linked to emotional, behavioural and physical problems (Ahlqwist *et al.*, 2008). It has been shown that lower back pain has an effect on the activation and endurance of the trunk musculature in tennis players during fatiguing isometric tasks (Correia *et al.*, 2016). However, muscle activation and kinematics during the tennis serve have not yet been tested.

1.3 Aim of the Study

The aim of this study is to compare lower quarter muscle activation and kinematics during the different phases of the tennis serve between adolescent tennis players with lower back pain and those without. A further aim is to look at other factors that could influence the risk of injury during the tennis serve between adolescent tennis players with and without lower back pain.

1.4 Objectives of the Study

The objectives of this study are as follows:

- To compare the muscle activation of the lower quarter muscles during the different phases of the tennis serve in adolescent tennis players with and without lower back pain.

- To compare the joint angles of the lower quarter (kinematics) during the different phases of the tennis serve in adolescent tennis players with and without lower back pain.
- To compare the demographic history and behaviour, active Range Of Motion (ROM), and dynamic lower limb balance in adolescent tennis players with and without lower back pain.
- To determine the relationship between active ROM, dynamic lower limb balance, kinematics, and muscle activation during the serve in adolescent tennis players with and without lower back pain.

1.5 Hypothesis

Alternate Hypotheses

- Adolescent tennis players with lower back pain do not use the same percentage of muscle activation and degree of joint angles in the lower quarter during the different phases of the tennis serve, when compared to players without lower back pain.
- Significant differences with regard to the demographic history, active ROM and dynamic lower limb balance can be identified between tennis players with and without lower back pain.
- There is a relationship between the active ROM, dynamic lower limb balance, joint angles and muscle activation in tennis players with and without lower back pain.

Null Hypotheses

- There is no difference in the lower quarter muscle activation and joint angles between adolescent tennis players with and without lower back pain.
- There are no differences in the demographic history, active ROM and dynamic lower limb balance between tennis players with and without lower back pain.
- No significant relationships can be identified between the active ROM, dynamic lower limb balance, joint angles and muscle activation between tennis players with and without lower back pain.

1.6 Significance of the Study

Gibbons and Comerford (2001a) report that the neuromuscular system can be rehabilitated when there is an injury or dysfunction. It has been shown that correct kinetic control and muscle activation have an effect on the modulation of the central nervous system (Hodges and Tucker, 2011). In turn, this has an effect on pain output. As health care providers, it is our duty to assist these players in the correct maintenance and implementation of preventative strategies in order for them to give of their best on the court. If this issue is addressed during adolescence, it could reduce the high incidence of lower back pain and chronic pain in the future.

The purpose of this study is to identify and analyse the differences in demographic history and behaviour, active ROM, dynamic lower limb balance, kinematics and muscle activation during the serve of adolescent tennis players with and without lower back pain. Essentially, if the differences in the chosen variables can be identified, we can correct the appropriate variables to improve the sport-specific technique. Identifying the variables could also equip

the player with correctly balanced training programmes in order to prevent injury and facilitate rehabilitation. The effectiveness of these injury-prevention programmes can then be determined in future research.

1.7 Organisation of the dissertation

On embarking on a research quest, the researcher's task may initially appear to be daunting. However, after the literature review, the thirst for knowledge is awakened – Chapter Two. Once one reaches down the rabbit hole of discovery, the next chapter virtually flows in a rhythmical methodical pattern – Chapter Three. Finally, the end brings results that are worthy of some discussion – Chapters Four and Five. This study has been structured according to the chapters shown in Figure 1.1.

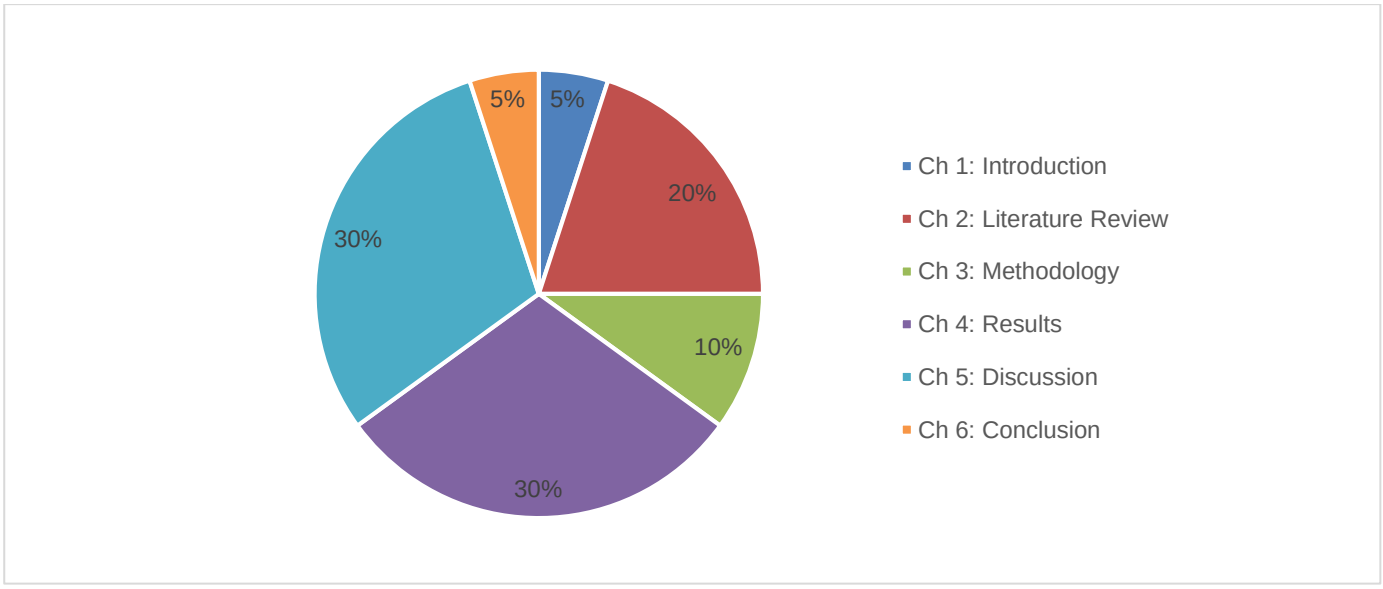


Figure 1. 1 Explanation of the Layout for this Dissertation

CHAPTER 2: LITERATURE REVIEW

A comprehensive search of the relevant literature was carried out to look at all aspects relating to adolescent tennis players. The dissertation title and study objectives were used in order to fine-comb and review the available research. Keywords that were used included lower quarter, motor control, kinematics, muscle activation, adolescents, tennis, back pain, tennis injury, tennis biomechanics, serve, Star Excursion Balance Test, SEBT, electromyography, EMG, inertial measurement units, IMUs, range of motion, ROM, self-report questionnaires, as well as combinations of the above keywords. Numerous electronic databases were used, including: EBSCO, Elsevier, Medline, Mendeley, Physiotherapy Evidence Database, PubMed, ResearchGate, Science Direct. With the available literature at her fingertips, the researcher was guided in establishing a valuable basis from which to build all further steps for this dissertation.

The epidemiology, occurrence, and aetiology of injury, and especially lower back injury in adolescent tennis players will be discussed. Extrinsic and intrinsic contributing factors, including motor control, muscle activation, and the kinematics of the lower quarter, will be elucidated. Reference will also be made to the management of and prevention strategies for lower back pain in adolescent tennis players. Finally, instrumentation that can be used to determine dynamic lower limb balance, kinematics and muscle activity will be discussed in the last section of the literature review.

2.1 The Magnificent Sport: Tennis

It is estimated that 17.96 million people played tennis in the USA during 2015 (*Tennis Participation and 'Play Occasions' increase in the U.S in 2015*, 2015). According to the Tennis Industry Association, tennis was the fourth-most popular sport in the world in 2012. Andy Murray, a professional tennis player had the following to say: "I love tennis because physically it's one of the most challenging sports; mentally, it's like a chess match; and it's just you out there to take all the glory or all the blame."

Tennis is truly a tri-factor sport and requires mental stamina to withstand the pressure of competitive sport. Tennis players also need to equip themselves with technical skills during this fast-paced sport. In addition, physically, tennis demands that a player should constantly change direction and speed. A balance between these three factors enables the tennis player to consistently win matches.

Roger Federer, currently ranked as the World's number 3 player in men's singles tennis, commented as follows: "Tennis can be a very frustrating sport. There is no way around the hard work. Embrace it. You have to put in the hours because there is always something you can improve. You have to put in a lot of sacrifice and effort for sometimes little reward but you have to know that, if you put in the right effort, the reward will come." These two quotations give us an insightful view into why so many people worldwide are passionate about and love to play tennis.

2.2 Epidemiology, occurrence and aetiology of injury

According to Geyer (2010), the career of an average tennis professional lasts approximately six years. This player wins 42% of his matches, 0.39 titles per year, and achieves the highest-ranking position of 152.1 (Geyer, 2010). In professional tennis players, withdrawal or retirement from tennis is either due to a deteriorating performance level or injury (Geyer, 2010; Hartwell, Fong and Colvin, 2017). The medical withdrawal rate in the USA Tennis Association's Junior National Tennis Tournaments was 16.9 per 1 000 for boys *versus* 14.0 per 1 000 for girls (Jayanthi, O'Boyle and Durazo-Arvizu, 2009). Medical withdrawals increase as age increases (Jayanthi, O'Boyle and Durazo-Arvizu, 2009). In addition, Geyer (2010) reports that the hazard rates challenging all players decrease for the first seven years of their career and increase thereafter, which leads to a U-shaped graphical representation of hazard rates. Injury rates in adolescents have been estimated to be from two to twenty injuries per 1 000 hours of tennis played (Abrams, Renstrom and Safran, 2012). Injuries are commonly related to microtrauma, overuse or acute incidents (Kibler and Safran, 2005).

An injury is defined by Pluim *et al.* (2006) as a musculoskeletal problem requiring a reduction or an interruption in tennis activity for any length of time, with or without evaluation or treatment by a health care provider. Injuries can be divided into two categories: acute and recurrent injuries. Acute injuries are defined as the first onset of an injury that disables players and prevents them from performing at a hundred percent of their potential. Recurrent injuries are defined as an injury to the same area and of the same type within a 12-month period (Hjelm, Werner and Renstrom, 2012). Participation in tennis, especially at elite levels, places players at risk for musculoskeletal injuries (Abrams, Renstrom and Safran, 2012). There is a prevalence of more lower-quarter injuries as opposed to upper-quarter injuries, and thirdly, trunk injuries in tennis players (Pluim *et al.*, 2006; Abrams, Renstrom and Safran,

2012). Lower quarter injuries are typically acute in nature (Kibler and Safran, 2005; Pluim *et al.*, 2006; Abrams, Renstrom and Safran, 2012). Acute medical conditions occur at a rate of over twice that of gradual-onset medical conditions and cause retirement from tournaments at a rate three times that of gradual-onset medical conditions (Hartwell, Fong and Colvin, 2017).

In Swedish junior tennis players, ankle injuries were reported as the most common acute injury (prevalence 2.4%), and lower back pain as the most common chronic injury for the lower quarter (prevalence 3.4%) (Abrams, Renstrom and Safran, 2012; Hjelm, Werner and Renstrom, 2012). In Greek tennis players, 80% of the injuries were found to occur during a tennis game and 20% during tennis practice (Malliou, 2015). In these players, lower-extremity injuries were reported in 32%, upper-extremity injuries in 30%, and the trunk accounted for 38% of the total injuries reported. Furthermore, in their study, Malliou reported that chronic injuries amounted to 67%, and acute injuries to 33% of the total injuries (Malliou, 2015). In a study by Kachanathu, Kumar and Malhotra (2014), 15,8% of Indian tennis players reported an injury that kept them from play for at least a week. The injuries comprised of upper- and lower-extremity injuries. However, no back injuries were specifically reported.

The most common injuries to the lower extremities include muscle sprains and strains of the adductors, hamstrings and gastrocnemius musculature, patellofemoral disorders, including Osgood-Schlatter's syndrome, medial collateral ligament injuries, Sever's apophysitis, tibial periostitis and ankle sprains (Kibler and Safran, 2005; Abrams, Renstrom and Safran, 2012; Kachanathu, Kumar and Malhotra, 2014).

When considering back and trunk injuries, the following overuse injuries have been reported: intervertebral disc herniation and degeneration, facet joint impingement, spondylosis, spondylolisthesis, abdominal muscle strains (acute and chronic) and muscle imbalances (Kibler and Safran, 2005; Abrams, Renstrom and Safran, 2012; Kachanathu, Kumar and Malhotra, 2014; Okholm Kryger *et al.*, 2015).

By the age of 18, 48% of adolescents will have experienced lower back pain (Andersen, Wedderkopp and Leboeuf-Yde, 2006). The prevalence of back pain among active athletes has been reported to be up to 85% (Abrams, Renstrom and Safran, 2012). In Japan, 61.6% of youths participating in competitive sports experienced lower back pain (Hangai *et al.*, 2010). Approximately 20% of adolescent tennis players suffer from lower back pain (Pluim *et al.*, 2006; Hjelm, Werner and Renstrom, 2012). It has been reported that one-half of elite tennis players suffer from back pain, and 38% of them had to miss a tournament on account of back pain (Kibler and Safran, 2005; Abrams, Renstrom and Safran, 2012). In fact, a large proportion (29%) suffered from chronic back pain (Abrams, Renstrom and Safran, 2012). The greatest risk factor to injury has been found to be previous injury, regardless of the body location (Hjelm, Werner and Renstrom, 2012).

Many elite adolescent tennis players aim to make their sport a profession in the future. As we can see from the literature, there is a high incidence of injury to the trunk or spine worldwide. Injury affects adolescent tennis players' chances to learn and perform in their sport. A high incidence of withdrawals has been reported, as well as a high risk for chronic injury. In contrast to the finding that lower back pain in adults may cause a deterioration in their quality of life, Fontecha *et al.* (2011) found that adolescents do not seem to experience

a deterioration in their quality of life on account of chronic back pain. This emphasises the importance of identifying early preventative and management strategies to assist the adolescent player as he/she grows and matures into an adult player.

In order to better understand tennis injuries, as well as the management and prevention strategies, we need to identify the extrinsic and intrinsic risk factors that could contribute to injury in tennis players.

2.3 Extrinsic Contributing Factors

2.3.1 Tennis Strokes

Stroke production in tennis involves generating repetitive forces and motions that are of high intensity and short duration (Johnson and McHugh, 2006). There are five basic tennis strokes: serve, forehand, backhand, volley and overhead (Iranshad, 2018; Elliott *et al.*, 2013). Each stroke poses its own technical demands, motor control requirements, and forces at play through the kinetic chain (Kibler and Safran, 2005; Iranshad, 2018). The serve and groundstrokes (forehand and backhand) are seen as the most explosive strokes (Kovacs, 2006). Optimal stroke execution is influenced by solid contact between the racquet and ball, controlled by grip strength (Kovacs, 2006). Magnetic Resonance Imaging (MRI) scan findings in elite adolescent tennis players generally describe an increase in rotational forces, particularly during the serving and groundstrokes (Alyas, Turner and Connell, 2007).

During a player's service game, the serve is the most commonly performed stroke during that phase of a tennis match (Johnson and McHugh, 2006). Johnson and McHugh (2006), reported that the winner of the 2003 USA Open averaged 7.8 serves per game for the 31

service games analysed. Over the two-week period of the tournament, he played seven matches, including approximately 120 service games. Therefore, it is estimated that he executed over 1 000 serves in singles match play alone when factoring in serves in tiebreakers.

The serve is reported to be the cause of most of the overuse injuries (Kovacs and Ellenbecker, 2011c). The serve requires power and acceleration to move quickly through the movement (Johnson and McHugh, 2006). It is repetitive in nature and needs to be practised religiously to be performed exceptionally (Kovacs and Ellenbecker, 2011a). Finally, the generation and transfer of torque and forces during the serve seem to have a higher impact on the trunk segment of the body (Chow, Shim and Lim, 2003; Campbell *et al.*, 2013).

2.3.2 The Serve

There are three most commonly used types of service or serve mentioned in the literature: flat, slice and kick (Abrams *et al.*, 2014; Byon, 2019). The flat and slice are taught as the strokes to use as the first serve. The flat and slice serves are similar in swing pattern and toss, with a similar contact point (Abrams *et al.*, 2011). The kick serve is usually used for the second serve. The kick (often called topspin) serve is hit from low to high: once the racquet drops below the shoulder, the player hits the ball while the racquet is accelerating upwards (Byon, 2019).

Abrams *et al.* (2014), indicated that the kick serve places a greater amount of force and torque on the back and shoulder, while the slice may be less stressful on the elbow and

wrist as opposed to the other service types (Abrams *et al.*, 2014). The flat serve involves the largest forward (flexion in trunk and rotation in shoulder) components of linear velocity at the racquet (Abrams *et al.*, 2011; Campbell *et al.*, 2013). However, no major differences were found in eight lower trunk muscles during the flat, slice and kick serves (Chow, Shim and Lim, 2003).

Traditionally, the serve has been divided into five phases for analysis: (1) windup; (2) cocking (early and late); (3) acceleration; (4) deceleration; (5) and follow-through (Chow, Shim and Lim, 2003; Roetert, Ellenbecker and Reid, 2009; Abrams *et al.*, 2011; Correia *et al.*, 2016).

In 2011, Kovacs and Ellenbecker (2011) published an eight-stage model that is a more detailed analytical tool. The eight stages are divided into three phases: preparation phase (store potential energy), acceleration phase (release kinetic energy), deceleration phase (follow-through motion) (Kovacs and Ellenbecker, 2011c).

The eight stages are described as: (1) the starting point of the serve (the preparation phase); (2) ball release from the non-dominant hand; (3) loading of the lower quarter; (4) the cocking point, when the racquet is facing vertically down; (5) motions from cocking until ball contact (the acceleration phase); (6) the short period of ball and racquet contact; (7) the motion from ball contact until the end of the serve (the final phase of deceleration); (8) and the finish point of the serve, seconds before a change in direction to prepare for the next stroke.

The eight-stage model can be seen in Table 2.1 and was developed by Kovacs and Ellenbecker (2011).

Table 2. 1 Stages of the Serve developed by Kovacs and Ellenbecker (2011b)

Three Phases		Eight Stages	
Preparation Phase	From the first sign of movement until maximum external rotation of the shoulder, which coincides at the point when the tip of the racquet head points toward the ground	1. Start	
		2. Release: From the start stage (ball and racquet at rest) until the ball is released from the non-serving hand	
		3. Loading: From the release stage until a fully loaded lower body position. This position coincides with the lowest vertical position of the elbow and also maximum knee flexion	
		4. Cocking: From the end of the loading stage until maximal shoulder external rotation, coinciding with the tip of the racquet head pointing toward the ground	
Acceleration Phase	Begin from maximum external rotation of the shoulder until the end of ball contact	5. Acceleration: From the end of the cocking stage until contact	
		6. Contact: The very short period where ball and racquet impact	
Deceleration Phase	Begins immediately post ball contact and continues through to the end of the service motion	7. Deceleration: Following contact until the end of upper and lower body deceleration of the serve	
		8. Finish: The short period at the end of deceleration and before the initial movement to prepare for the next stroke	

Trunk rotation velocity has been reported to be around 350 degrees per second in adult tennis players (Kibler and Safran, 2005). Fifty-four percent (54%) of the total force is developed in the leg/hip/trunk link and 21% in the shoulder (Hjelm, Werner and Renstrom, 2012). Baiget *et al.* (2016) found that the maximum isometric strength of the leg and back muscles cannot be linked to the velocity of the serve. The only maximum isometric strength that was found to be linked to the serve velocity was from the internal rotation of the shoulder (Baiget *et al.*, 2016). The range of the average ball speed during a serve in elite adolescent tennis players lies between 50 and 100 mph (80-160 km/ph).

Elliott (2006) reports that the key to the recovery of elastic energy is the timing between the stretch and the shortened phases of the motion. A more powerful serve can be attained by rotating segments faster and preparing the body physically for higher speed movements (Elliott, 2006). Interestingly, the velocity of the serve could be increased from a six-week specific upper- and lower-quarter exercise programme (Kara *et al.*, 2015). However, the repeated demands to produce force by muscle shortening can cause a cycle of microtrauma to the tight muscles, followed by scar formation, followed by more microtrauma with continued use (Kovacs, 2006). This is exacerbated through incorrect technique. Therefore, the kinematics and force generation strategies during the serve could have an effect on the risk of injury.

2.3.3 Skill level

Compared to beginner servers, elite servers display earlier muscle activation and a quicker acceleration phase during the serve (Kovacs and Ellenbecker, 2011c). The fewer number of years playing tennis could be a risk factor for sustaining an injury (Hjelm, Werner and Renstrom, 2012). Some injuries, that include lateral epicondylitis, are seen more often in

recreational tennis players (Kibler and Safran, 2005). It has been found that there is an increase in the vibrational impact of the racquet in amateur players when compared to experienced players (Abrams, Renstrom and Safran, 2012). However, in contrast, in a study done by Kachanathu *et al.* (2014) on Indian tennis players, it was found that higher ranked tennis players are more at risk for injury. Pluim *et al.* (2006) reported no statistical differences in the incidence of overall injury and prevalence rates across all skill levels in recreational athletes. Furthermore, there is no conclusive evidence to suggest that skill level has a direct effect on risk for injury. However, skill level does affect technique (Kovacs and Ellenbecker, 2011a; Hjelm, Werner and Renstrom, 2012), which in turn may increase the risk of injury.

2.3.4 Volume of Play

There is a significant increase in the risk of medical withdrawal beyond the fourth match played in a tennis tournament (Jayanthi, O'Boyle and Durazo-Arvizu, 2009). Fatigue from maximal tennis hitting has resulted in a 69% deterioration in the hitting accuracy of groundstrokes and a 30% decline in the accuracy of the serve (Kovacs, 2006). Hangai *et al.* (2010) report that the duration of competitive sports during youth, are associated with lower back pain and symptoms in the lower extremities.

Playing tennis for more than six hours per week has been shown to increase the risk of back pain in adolescents (Hjelm, Werner and Renstrom, 2012). However, from other studies, it appears that total playing time is between only 20% and 30% of the total match time (Kovacs, 2006). Most high-level matches consist of a work-to-rest ratio of between 1:2 and 1:5, with winning points having an average length of between three seconds on some of the faster surfaces (grass, carpet, and indoor) to close to 15 seconds (Kovacs, 2006). Fatigue has been shown to reduce proprioceptive ability, which may lead to protective mechanisms

being too slow in their response in order to prevent injury (Kovacs, 2006). A reduction in protective mechanisms could lead to an increase in torque and force in the kinetic chain. Ultimately, an increase in the volume of play has an effect on injury rate (Abrams, Renstrom and Safran, 2012).

2.3.5 Equipment

Equipment for a tennis match includes tennis balls, shoes, apparel and racquet (Ogle, 2018). There are tennis balls of different sizes to choose from for beginner players and/or for specific court surfaces. Shoes and apparel need to provide lightweight performance, stability and breathability. No studies have been found that have looked at the effect of various training balls, shoes or apparel on the risk of injury in adolescent tennis players. Racquet length, weight, head shape, grip size and type of strings can affect how a player hits the ball. Currently, various accessories for a racquet are available, including: over-grips, vibration absorbers and lead tape that can personalise the properties of the racquet.

Different grip positions may affect the stroke biomechanics, vibrations and overall biomechanical loads transmitted through the kinetic chain (Abrams, Renstrom and Safran, 2012). The less frequent racquet vibrations are experienced, the lower the injury rate (Kibler and Safran, 2005). Hand placement can result in ulnar-sided injuries (more commonly caused by the semi-western and western grips) or radial-sided injuries (more commonly associated with the eastern grip) of the upper limb (Abrams, Renstrom and Safran, 2012). From the literature, it is evident that the hand grip does not have a direct effect on the risk of lower back injury in adolescent tennis players; however, hand grip may have an effect on the stroke biomechanics. The different hand grips are displayed in Figure 2.1.

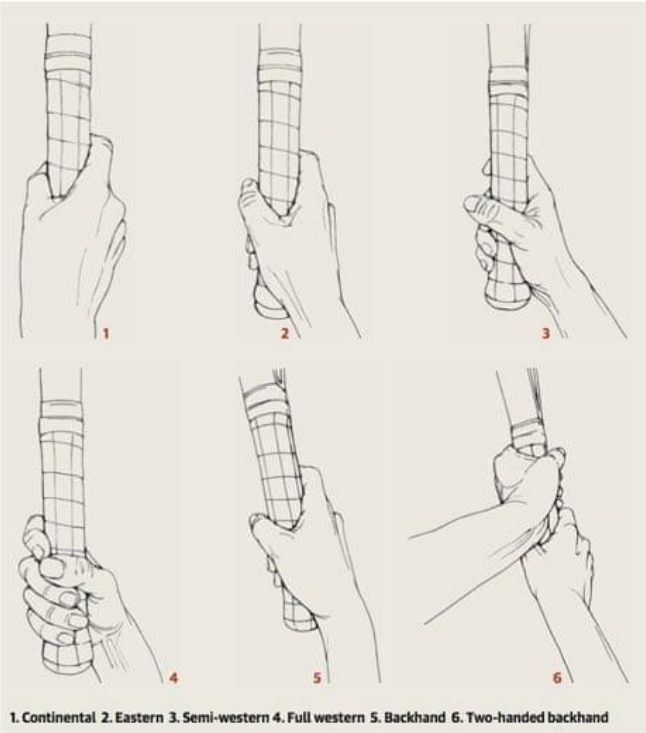


Figure 2. 1 Different types of hand grip positions (Guardian, 2019)

2.3.6 Court Surfaces

Clay courts slow the ball down, while grass, synthetic and hard courts speed the ball up (Kibler and Safran, 2005). This has an effect on the duration of a match, as well as the force generated to effectively hit the ball. Fewer injuries have been reported when playing on clay courts as opposed to hard courts (Abrams, Renstrom and Safran, 2012; Malliou, 2015). Okholm Kryger *et al.* (2015) reported that trunk injuries are significantly more frequent on grass than on hard courts for women, and on clay for men. However, Hartwell *et al.* (2017) reported that women are more than four times more likely to injure themselves on clay courts as opposed to hard courts during pro circuit tournaments. Other studies have reported that grass courts are associated with the least number of incomplete matches, with hard courts showing the largest number (Abrams, Renstrom and Safran, 2012). Court surfaces may play a role in injury rates (Kibler and Safran, 2005; Malliou, 2015) or may play a role in time and

force generation during play, which could then have an effect on the injury rates (Hartwell, Fong and Colvin, 2017).

2.3.7 Warm-Up

It has been reported that tennis players who tend to neglect a proper warm-up before playing are more prone to injuries (Kibler and Safran, 2005; Kachanathu, Kumar and Malhotra, 2014; Malliou, 2015). The incidence of injury among tennis players can be reduced by a warm-up programme (Kachanathu, Kumar and Malhotra, 2014). Kovacs (2006) reports that it would be remiss to suggest that tennis is a predominantly aerobic sport; it might be better to classify it as an anaerobically predominant activity requiring high levels of aerobic conditioning to avoid fatigue and aid in recovery between winning points (Kovacs, 2006). A warm-up programme activates the muscle fibres and improves flexibility before commencement of play. However, evidence suggests that static stretching, as part of a warm-up programme, does not reduce overall injury rates (Hjelm, Werner and Renstrom, 2012). Warm-up programmes will need to include aerobic and anaerobic strategies to cover speed, strength, stability and flexibility aspects required for the sport. This has also been reported in the planning and periodisation of programmes for professional junior tennis players (Reid *et al.*, 2009).

2.4 Intrinsic Contributing Factors

2.4.1 Adolescence and Age

According to the Canadian Paediatric Society, adolescence begins with the onset of physiologically normal puberty and ends when an adult identity and behaviours are accepted (Findley, 2003). Puberty is seen as the period where skeletal, sexual and somatic changes occur (Ochi and Campbell, 2009). This period of development corresponds roughly to the

period between the ages of 10 and 19 years, which is consistent with the World Health Organisation's definition of adolescence (Findley, 2003; *Adolescent Health*, 2017).

Exercise plays a vital role in the healthy development of an adolescent, during this period of life. However, it is exceptionally difficult to master a balance between "too much" and "too little" during the stages of pre-puberty, puberty and post-puberty. For instance, poor isometric muscle endurance in the back extensors has been linked to lower back pain in adolescents (Andersen, Wedderkopp and Leboeuf-Yde, 2006). Auvinen *et al.* (2009) report that musculoskeletal pain in multiple areas is common in 16- to 18-year-old adolescents. A steep increase in the prevalence of lower back pain has been reported for all youths during puberty (Burton *et al.*, 1996; Andersen, Wedderkopp and Leboeuf-Yde, 2006). Furthermore, growth spurts also occur in the adolescent years and in their turn affect balance, footwork, movement and coordination (Ochi and Campbell, 2009). These are important aspects that adolescent tennis players strive to perfect.

Interesting to note, is that age is not significantly correlated with injury rate in tennis players across a variety of skill levels (Jayanthi, O'Boyle and Durazo-Arvizu, 2009). Biological age is a relevant factor to consider when it comes to examining the progression and intensity of a physical work-out (Ochi and Campbell, 2009), as in the case of high-performance tennis players. Puberty should be analysed and taken into consideration during the planning of training sessions. High levels of repetition and low-intensity training are recommended to improve performance and minimise the risk of injury (Ochi and Campbell, 2009). Kovacs (2006) reports that training should concentrate on technical stroke production, with less emphasis on physical conditioning until tennis players reach puberty.

2.4.2 Sex

Male and female differences include the role of hormones, differential anatomy, joint stability and bone quality (Wolf *et al.*, 2015). Bone mass has an effect on kinematics for men, while women often have a higher injury rate on account of hormonal changes (Ahlqwist *et al.*, 2008). Differences in the frequency of injury between the two can also be attributed to the type of sport that society directs the sexes to participate in (Stracciolini *et al.*, 2015). These differences between male and female players could have an effect on the risk of injury.

In the USA pro circuit tournaments, men had over twice the overall rate of injury compared to women. Men also had over three times the injury rate that resulted in withdrawal from a match (Hartwell, Fong and Colvin, 2017). Another study in professional tennis players reported women left tournaments due to injury, significantly more frequently than men (Okholm Kryger *et al.*, 2015). Okholm Kryger *et al*. (2015) further reported that back injuries accounted for 18.6% of all male injury-related departures, while for women, these regions accounted for 11.0% of their injury-related departures. It has been shown that adolescent girls experience more injuries to the lower back than their counterparts (Ahlqwist *et al.*, 2008; Stracciolini *et al.*, 2015). The studies by Hartwell *et al*. (2017) and Okholm Kryger *et al*. (2015) both reported the prevalence of injury in adult tennis players. There is however minimal evidence from research to report significant differences between the two sexes in respect of injuries relating to adolescent tennis players (Pluim *et al.*, 2006; Abrams, Renstrom and Safran, 2012; Kachanathu, Kumar and Malhotra, 2014).

2.4.3 Dominance

Tennis players demonstrate asymmetric hypertrophy owing to the one-sided dominant nature of this sport. Often tennis-specific imbalance is present in the dominant shoulder

whereby the internal rotators are overly developed relative to the external rotators (Roetert, Ellenbecker and Reid, 2009). The dominant arm has been reported to have an increased risk of overuse injuries (C. Martin *et al.*, 2014). In the lower quarter, asymmetry has been reported in the erector spinae (ES), external obliques (EO), gluteus maximus (GM), iliopsoas and rectus abdominis (RA) muscles (Abrams, Renstrom and Safran, 2012; Hjelm, Werner and Renstrom, 2012; Correia *et al.*, 2016). No evidence was found to specifically identify an increased risk of injury on account of imbalance in the dominant or non-dominant limb in the lower quarter. However, dominance could play a role in tennis strokes, muscle activation and kinematics. Therefore, dominance of the upper and lower limb is noted in the forthcoming demographic questionnaire and the testing procedures for dynamic lower limb balance and the tennis serve. Establishing limb dominance will be an important factor to consider when analysing the study variables.

2.4.4 Imaging

According to an MRI scan of a sample of 33 asymptomatic elite adolescent tennis players, 80% were found to have abnormalities (Alyas, Turner and Connell, 2007). Abnormal changes were seen in their facet joints (69.7%). Other abnormalities included synovial cyst formation (30.3%), disc degeneration and herniation (39.4%) and pars inter-articularis injuries (27.3%) (Alyas, Turner and Connell, 2007). Furthermore, evidence on MRI scans of a sample of 188 young athletes showed active spondylolysis in 45.7% of the sample group, with negative findings on plain radiography (Kobayashi *et al.*, 2013). In a further sample of 12 young athletes with unclear findings on plain radiography, the MRI results showed active spondylolysis in 91.7% of the sample group (Kobayashi *et al.*, 2013). Overall, 90% of the young athletes belonging to the group without spondylolysis and 88.1% of those belonging to the group with spondylolysis, that was both screened with MRI scans, experienced pain

during lumbar spine extension which has been described as a diagnostic test for lumbar spondylolysis (Kobayashi *et al.*, 2013). Although functional X-ray and MRI scans could give us interesting inputs, they have not contributed to the physical testing and outcomes of this study. Therefore, no imaging was done or even considered for this study.

2.4.5 Range of Motion (ROM)

In tennis players, a decrease in active ROM has been linked with muscle weakness, a reduction in flexibility and/or direct injury (Kovacs, Ellenbecker and Kibler, 2010). Hjelm *et al.* (2012) found that a decrease in ROM takes place in multiple joints in adolescent tennis players who sustained injuries. Furthermore, bone growth in adolescents can also have an effect on muscle flexibility and strength (Kibler and Safran, 2005). Kibler and Safran (2005) also reported that players often have a decreased internal rotation and an increased external rotation in the dominant shoulder joint (Kibler and Safran, 2005; Pluim *et al.*, 2006). Young *et al.* (2014) conducted a study to look at hip ROM and its association with injury in female professional tennis players. They reported that the mean internal rotation was greater than the mean external rotation in both the dominant and non-dominant hips and in both the flexed and prone positions (Young *et al.*, 2014). However, no association was established between hip rotation and risk of injury.

A decrease in the internal rotation of the leading hip and a deficit in the extension of the lumbar spine have been reported in tennis players (Hjelm, Werner and Renstrom, 2012). These deficits have been associated with lower back pain (Kibler and Safran, 2005). In a lumbo-pelvic kinematics study of adults with and without lower back pain, Laird *et al.* (2014) found that people with lower back pain experience a decrease in lumbar ROM, move more

slowly and have reduced proprioception. People with lower back pain have been shown to favour hip contribution *versus* lumbar contribution during lumbar flexion (Laird *et al.*, 2014). Furthermore, a decrease in ROM has been reported in cervical lateral flexion of the dominant side in players with back pain (Hjelm, Werner and Renstrom, 2012). As opposed to other athletes, tennis players have also been shown, while serving, to present with a reduction in the muscle length of both hamstrings, especially in the back leg (Kovacs, 2006).

It has been suggested that an assessment of the ROM of the hips and the lumbar spine could be a tool for preventing back pain, especially in the experienced player such as recreational tennis players (Malliou, 2015). This supports the theory that an imbalance in the kinematics of the biomechanical chain can lead to possible injury. The lack of muscle flexibility has an effect on ROM in multiple joints and this could cause maladaptive biomechanics.

2.4.6 Dynamic Lower Limb Balance

Dynamic lower limb balance is the movement of the centre of gravity outside the base of support (Kovacs, 2009). Single leg control is an important requirement for the tennis player during a match. The analysis of coordination, balance, proprioception and motor control has been an ongoing research question; however, this has not been well researched in the adolescent tennis population. Poor dynamic balance strategies have been linked with lower limb injuries in college football and other types of sport (Leavey, Sandrey and Dahmer, 2010; Butler *et al.*, 2013). Growth spurts in the young tennis player that affect balance, footwork, and movement patterns, as well as coordination, have also been reported (Ochi and Campbell, 2009).

Balance-training regimes have been shown to: (1) improve static and dynamic balance, (2) improve proprioception, (3) reduce lower limb strength asymmetry and, (3) reduce sports-related injuries (Emery *et al.*, 2005; Valovich Mcleod *et al.*, 2009; Sannicandro *et al.*, 2014). The medical practitioner is constantly searching for a tool that can effectively and quickly evaluate the dynamic lower limb balance in order to reduce the risk of injury for the athlete.

2.4.7 Motor Control and the Kinetic Chain

The kinetic chain theory was introduced to explain the transfer of forces from the lower limb, through the trunk, through the upper limb, and to the racquet (Abrams *et al.*, 2011). Motor control encompasses the working relationship between the neuropathways and motor units in order to produce coordinated functions. The key lies in initiating and directing movement, while grading the intensity of muscle contraction. Changes in the kinetic chain and motor control of a tennis player could lead to imbalance and injury. Therefore, lower quarter muscle activation and kinematics can also be regarded as intrinsic risk factors for lower back pain.

Muscles can be classified into local stabilisers, global stabilisers and global mobilisers (Comerford and Mottram, 2012). These muscles consist of slow and fast motor units and can function at a low or high threshold (Comerford and Mottram, 2012). The trunk or lower quarter musculature used in this study often plays a multi-tasking role by functioning in more than one of these categories. These respective muscles are recruited in force couples during a demanding task such as the tennis serve. The EO, ES (spinalis) and GM (posterior fibres) are classified as global stabilisers. Global stabilisers generate eccentric force to control the range through movement (Gibbons and Comerford, 2001a). The aim of this coupled force generation is to produce movement with stability (Gibbons and Comerford, 2001a). Furthermore, the RA, ES (iliocostalis) and GM can be classified as global mobilisers. Global

mobilisers work concentrically to produce power and speed, and work eccentrically to decelerate high loads (Gibbons and Comerford, 2001a).

The alterations of energy flow from the trunk to the racquet can play a predictive role in both the performance of the serve and injury (Martin *et al.*, 2014). Tennis players are required to be exceptional movers in a linear direction, but also laterally and multiple directions (Kovacs, 2006). The synchrony of the kinetic chain through muscle activation and joint kinematics is the key to successful movement (Kovacs, Ellenbecker and Kibler, 2010). On looking at the serve, it is worth noting that if any of the links in the chain are not synchronised effectively, the outcome of the serve will not be optimal (Kovacs, Ellenbecker and Kibler, 2010), and could lead to injury.

Campbell *et al*. (2013) report that during the serve, tennis players with lower back pain typically use less right rotation during the drive phase and more left lumbar rotation during the forward swing phase (Campbell *et al.*, 2013). Tennis players with lower back pain have shown an increase in lateral flexion during the serve and a reduction in ES activation during the preparation phase (Chow, Shim and Lim, 2003; Correia *et al.*, 2016). The difficulty in movement could also be due to the summation of forces from the ground up through the kinetic chain and out into the ball (Kovacs and Ellenbecker, 2011c). Each phase of the serve can only be as effective as the proficiency of the phase before it (Kovacs and Ellenbecker, 2011c).

Chronic lower back pain is defined as persistent and disabling pain that lasts for more than three months. Pain inhibition leads to reduced function and the poor coordination of the

stability muscles (Gibbons and Comerford, 2001a; Ganesh, Chhabra and Mrityunjay, 2015). Local stabilisers control through translation, while global stabilisers control through movement (Gibbons and Comerford, 2001a).

Individuals with chronic lower back pain experience pain inhibition or the facilitation of muscles that are either the source of pain or the producers of painful movement (Hodges and Tucker, 2011). This may cause a change (shortening or lengthening) in the extensibility properties of the myofascial structures. (Comerford and Mottram, 2012). A dysfunction in the global stabiliser and mobiliser muscles can also cause inefficient and/or altered recruitment patterns (Comerford and Mottram, 2012). This can either occur in high and/or low threshold recruitment, which are both necessary in a tennis match.

Muscle imbalance, in terms of changes in strength and flexibility, can alter joint biomechanics and lead to a decreased maximal force output (Kibler and Safran, 2005; Hjelm, Werner and Renstrom, 2012). Changes in recovery, strength and endurance have been reported in the literature and these factors could have an effect on muscle balance. For example, multifidus muscle recovery is not spontaneous in the remission of painful symptoms (Hides, Richardson and Jull, 1996). In particular, paraspinal and other trunk muscle weaknesses have been documented in severe or chronic lower back pain (Ganesh, Chhabra and Mrityunjay, 2015). Furthermore, poor endurance of the back extensor muscles and greater strength of the trunk flexor muscles have been linked to lower back pain (Andersen, Wedderkopp and Leboeuf-Yde, 2006). Thus, as reported by Hides, Richardson and Jull (1996), a lack of localised muscle support may be a reason for the high recurrence rate of lower back pain following an initial episode of back pain.

Chow, Shim and Lim (2003) found no major differences in muscle activation patterns across the different types of serve in tennis-playing research participants. However, they found differences in muscle activation were more pronounced in the RA and EO than in the internal obliques and ES muscles, when comparing sides (Chow, Shim and Lim, 2003). Tennis players with lower back pain have been shown to present with lower levels of muscle endurance during the side bridge, especially in the abdominal muscles (Correia *et al.*, 2016). This may indicate different muscle activation and endurance strategies between sides and between participants. During movement, the body requires timely muscle activation throughout the kinetic chain under investigation. This includes eccentric and concentric muscle control. Furthermore, dynamic stability of the spine plays a role in the prevention of lower back pain (Correia *et al.*, 2016).

As in research findings by Lim, Chow and Chae (2012) into the golf swing, during the serve in tennis, activation patterns of the lower trunk muscles demonstrate a high degree of co-contraction (Chow, Shim and Lim, 2003). An imbalance between physical conditioning and the power of the stroke could determine an injury pattern (Kachanathu, Kumar and Malhotra, 2014).

As mentioned before, motor control can be divided into static and dynamic control. Static motor control, through local stabilisers, requires the stabilisation of the specific segment within the established base of support while minimising movement of the body segment (Gibbons and Comerford, 2001b; Ganesh, Chhabra and Mrityunjay, 2015). On the other hand, dynamic motor control, through global stabilisers, is equivalent to neuromuscular control through movement, thus maintaining the established base of support in order to

complete a functional task (Gibbons and Comerford, 2001a; Ganesh, Chhabra and Mrityunjay, 2015). These motor control principles need to be considered during the loading and unloading of the serve. Correia *et al.* (2016) report, symptomatic players, inhibit extensor muscle activity in order to avoid a painful contraction, that would prevent them from achieving greater endurance over a longer period of time. It has been reported that research needs to look at the excessive lateral spinal load during the tennis serve (Campbell *et al.*, 2013; Correia *et al.*, 2016).

When one segment is removed or altered in the kinetic chain, there is an increase in force in the remaining parts of the chain. This leads to overuse and injury. By controlling the kinetic chain, the tennis player will be able to improve performance and minimise the risk of injury (Elliott, 2006). It has been found that stabilisation of the lumbar spine during kinematics of the serve (flexion, extension and rotation) can be controlled through the co-activation of the lower trunk muscles (Elliott, 2006). It has also been found that over half of the force generated during the stroke's action is generated through the lower extremity and trunk musculature (Johnson and McHugh, 2006).

Inertial measurement unit systems are used to analyse kinematics and functional tasks, while, electromyography (EMG) can give a description of the muscle activity during the kinematics. These measurement tools can give us a clear explanation of the motor control strategies during the serve.

2.5 Prognosis, Management and Prevention of Lower Back Pain

Prognosis and return to play after injury are dependent on the extent of the injury and the requirements of the sport. Inevitably, the longer a player experiences pain, the poorer the prognosis of returning to the sport without pain will become. In a chronic pain study of adolescents, the probability of pain increased during a two-year follow-up, with participants reporting more areas of pain and a higher likelihood of pain (Auvinen *et al.*, 2009). This indicates the importance of early management and the implementation of continuous prevention strategies.

The prevention of injuries in junior tennis players should centre around the evaluation and modification of extrinsic and intrinsic risk factors for injury (Kibler and Safran, 2005). Furthermore, Perry *et al*. (2009) suggest the importance of identifying the interaction of multiple domains of risk factors (extrinsic and intrinsic) and subgroups of adolescents with back pain (Perry *et al.*, 2009). Also of fundamental importance is to understand how and when an injury occurs in order to generate better prevention strategies (Okholm Kryger *et al.*, 2015).

A strong and balanced kinetic chain is important in minimising the risk of injury. A study in Denmark of 9 346 adolescents showed that participants with high isometric endurance levels of the back extensor muscles had a lower risk of back pain (Andersen, Wedderkopp and Leboeuf-Yde, 2006).

Participation in more than one sport type has been linked to movement and total body strengthening (Ochi and Campbell, 2009). Abdominal and lower back exercise is also of

utmost importance in strength and rehabilitation programmes designed for tennis players (Chow, Shim and Lim, 2003).

Injury-prevention programmes include recommendations for competitive players to train to improve physical aspects such as strength, speed, power, flexibility, local muscular endurance and muscular balance (Baiget *et al.*, 2016). The importance of specific rehabilitation programmes and a return to physical activity has been shown as a preventative strategy (Ahlqwist *et al.*, 2008). For extremely active children, an episode of back pain should be followed by individualised rehabilitation, including exercises to improve neuromuscular control, technique, trunk stability, mobility, balance, and coordination, based on their particular activity (Ahlqwist *et al.*, 2008; Correia *et al.*, 2016). Pre-participation screening tools have also been shown to be reliable in identifying injury risk (Cook, Burton and Hoogenboom, 2006; Teyhen *et al.*, 2012).

Exercise and rehabilitation have been widely researched to mitigate the risk of injury and improve strength and performance (Kovacs, 2009; Leavey, Sandrey and Dahmer, 2010; Faigenbaum *et al.*, 2011; Kovacs and Ellenbecker, 2011a). The correct rehabilitation programme that includes biomechanical analysis and sport-specific training is vital in the process of recovery and the prevention of recurrent injury (Pluim *et al.*, 2006; Hjelm, Werner and Renstrom, 2012).

Neuromuscular training is focused on, amongst others, lower extremity strength and core stability which have been shown to significantly improve the results attained in the Star Excursion Balance Test (SEBT) in female soccer players (Filipa *et al.*, 2010). This type of

training should include education, musculoskeletal screening and adjustments to the equipment (Pluim *et al.*, 2006). However, players develop and progress at varying rates through different approaches or pathways. In fact, technical, tactical, physical, and mental goals need to be individualised for each player (Reid *et al.*, 2009).

2.6 Instrumentation

2.6.1 Star Excursion Balance Test (SEBT)

The SEBT was introduced by Gary Gray and has been used widely as a tool to measure dynamic lower limb balance (Gray, 1995). The main aim of the test is to measure lower extremity reach in order to predict the risk of injury, while challenging an individual's limits of dynamic stability (Hertel *et al.*, 2006; Gribble, Hertel and Plisky, 2012; Coughlan *et al.*, 2013; Ganesh, Chhabra and Mrityunjay, 2015). This test evaluates the human postural system and how the somatosensory, vestibular and visual inputs are integrated to generate the appropriate amount of movement (Coughlan *et al.*, 2013; Ganesh, Chhabra and Mrityunjay, 2015). Lower extremity tightness and balance have been shown to be significantly correlated during the SEBT (Endo and Sakamoto, 2014). Muscle activation of the lower extremity during the SEBT has also been shown to be direction-dependent (Earl and Hertel, 2001).

Variables that need to be taken into consideration for successfully completing the SEBT include learning effects, body height, leg length and gender (Kinzey and Armstrong, 1998; Ganesh, Chhabra and Mrityunjay, 2015).

Criteria that are used to determine whether a participant has effectively undergone the test include the following:

- the participant may not lift the weight-bearing or stance foot from the centre of the grid,
- the participant needs to maintain his or her balance,
- the participant needs to touch the line with the reach foot while continuing to bear full weight on the stance leg (Ganesh, Chhabra and Mrityunjay, 2015).

Ganesh *et al.* (2015), looked at the SEBT as a tool to identify reach deficits in adult participants with chronic lower back pain. Their results showed that after normalising the values to the leg length, all directions but the posterior direction demonstrated a greater mean reach in the control group (without chronic lower back pain), as opposed to the chronic lower back pain group (Ganesh, Chhabra and Mrityunjay, 2015).

The SEBT has not yet been used on tennis players. However, it has been cited in the literature as a valuable test for elite junior rugby players, high school basketball players, young female soccer players and college football players (Plisky *et al.*, 2009; Filipa *et al.*, 2010; Butler *et al.*, 2013; Coughlan *et al.*, 2013).

The normative data in SEBT can be used to monitor an individual's performance (Filipa *et al.*, 2010; Coughlan *et al.*, 2013). Furthermore, the SEBT can be incorporated in pre-participation examinations in order to identify the risk of injury (Plisky *et al.*, 2009; Butler *et*

al., 2013). For this reason, it was decided to use the SEBT in order to evaluate whether the adolescent tennis player's dynamic balance has an effect on his/her lower back pain status.

2.6.2 Inertial Measurement Unit (IMU) Systems

There are various types of IMU products that can be used for kinetic motion analysis that are currently on the market. IMU systems are changing the way we assess movement. Functional activities are analysed during gait, ergonomics, performing arts and sports.

An IMU is comprised of a three-dimensional accelerometer, gyroscope, and magnetic sensor, combined with a fusion algorithm – the Kalman filter (Sabatini, 2011; Al-Amri *et al.*, 2018). The Kalman filter, also called a linear quadratic estimation, is a sensor fusion algorithm that removes "noise" from a series of measurements in order to produce a more accurate measurement (Sabatini, 2011). An IMU can estimate the three-dimensional movement of a segment in space when attached to that body segment (Al-Amri *et al.*, 2018). When combined with other IMUs on adjacent body segments, the motion of the segment can be calculated in relation to the other parts.

Movement is assessed in three planes of motion, namely in the sagittal, frontal and transverse planes. The information captured is transmitted via a wireless connection to a laptop computer on which the processing of information is performed and visualised (Roetenberg, Luinge and Slycke, 2013).

2.6.3 Electromyography (EMG)

Wireless EMG can be used as a diagnostic measure and rehabilitative tool (Worrell, Crisp and LaRosa, 1998; Chow, Shim and Lim, 2003; Marshall and Murphy, 2003; Fauth *et al.*, 2010; Pozzi, Moffat and Gutierrez, 2015). Muscle activation can be investigated during dynamic movement as well as static postures. Muscle endurance in static postures, including maximum voluntary isometric contraction (MVIC), have been tested in adolescent tennis players with and without back pain (Correia *et al.*, 2016). EMG activity has also been used to indicate the general activation of the lower trunk muscles during different phases of the tennis serve and allowed for comparisons to be made between different serve types (Chow, Shim and Lim, 2003).

The neuromuscular feed-forward mechanism is necessary to produce a powerful tennis serve. In order to determine neurological fatigue, Kovacs *et al*. (2010) reported that functional tests that measure maximal mechanical power are preferred. Muscle activation should be at a higher level in non-fatigued muscles than in fatigued muscles (Kovacs, Ellenbecker and Kibler, 2010). They report that effective EMG technology can be used to compare pre- and post-activity force production characteristics, and thus create an objective assessment of the recovery state.

The purpose of the EMG test in this study was not to investigate the static endurance of the muscle in question, but rather to investigate the recruitment of muscle fibres and the possibility of pain inhibition in the neuromuscular feed-forward mechanism (Hodges and Tucker, 2011).

2.7 Conclusion of Literature Review

Malliou (2015) reported on the factors contributing to the mechanism of injury, that were identified by Greek tennis players. The participants identified: “inadequate warm-up”, “fatigue” and “high intensity”, but also “bad technique” and “step on the ball” as problem areas.

The literature review has given a glimpse into the important extrinsic and intrinsic risk factors that have an effect on injury status in adolescent tennis players. There is no doubt that lower back pain is a debilitating injury in adolescent tennis players with possible lifelong consequences. From the research, we can see that there are numerous management and prevention strategies that can be applied in order to address injury in tennis players. The question remains: Which management or prevention strategies would be the most effective? This highlights the importance of identifying specific risk factors.

The literature review emphasises the significance of this study. The decision was then made to use demographic history, active ROM, SEBT, IMU systems and EMG as variables to identify risk factors.

CHAPTER 3: METHODOLOGY

3.1 Type of Study

This study used a cross-sectional observational design.

3.2 Setting

The electronic self-report questionnaire was emailed to the participants for them to complete at home. Physical testing was conducted on a tennis court at the North Gauteng Tennis Club in Pretoria.

3.3 Participants

3.3.1 Source of Participants

Data were collected from May to August 2017. There were 138 junior tennis players, between the ages of 10 and 18, who were members of the North Gauteng Tennis Club in 2017. Junior tennis players were invited, with no prejudice or pressure, to participate in the study.

3.3.2 Sample Selection

A sample of convenience was used. In order to obtain a sample of significant size with a confidence interval of 95%, each group should have amounted to 13 members (n=13) (see Table 3.1). The expected frequency of adolescent tennis players with lower back pain was put at 20% by Pluim *et al.*, (2006). Tennis players were recruited for the study irrespective of their lower back pain status. It was calculated that a total sample of 50 participants was needed in order to meet the estimated sample size requirement (n=13) and to account for

the potential of missing data. This met the requirements of the population size and the expected frequency of tennis players with and without lower back pain. Thus, this particular sample selection can be regarded as a fragment (50) of the total source of participants (135) without regard to their lower back pain status (see Table 3.1).

Table 3. 1 Calculation of Sample Size

Proportion in control group (%):	100
Proportion in experimental group (%):	27
Alpha (%):	5
Power (%):	95
Dropouts (%):	10
n (per group):	13

n = participant number needed for each group

The following inclusion criteria were applied:

- Adolescent tennis players between the ages of 10 and 18 (Findley, 2003);
- Tennis players at the North Gauteng Tennis Club who played tennis at least once a week and had played tennis for at least three years prior to their selection for this research study (Correia *et al.*, 2016);
- *For the Lower Back Pain (LBP) group:* Participants who were currently struggling with pain in the lower back area and/or had experienced an episode of back pain where the tennis player had to stop playing on account of pain in the previous six months. [Lower back pain is defined as pain below the line of the 12th rib and above the inferior gluteal folds (Fontecha *et al.*, 2011).]

- *For the No Lower Back Pain (NLBP) group:* The adolescent participant did not currently have any back pain and had not experienced any back pain where he/she needed to stop playing on account of pain.

Tennis players were excluded from participating in the study on the basis of the following exclusion criteria:

- Other acute musculoskeletal injuries that would interfere and/or prevent the tennis player from executing the serve action. [An injury is defined by Pluim *et al*. (2006) as a musculoskeletal problem requiring a reduction in or interruption of tennis activities for any length of time with or without evaluation or treatment by a health care provider.]
- Metabolic conditions and genetic disorders that could affect muscle activation.
- Previous back surgery, tumours or infection.
- Diagnosed Scheuermann`s disease, ankylosing spondylitis, acute spondylolysis and/or acute spondylolisthesis.

The inclusion and exclusion criteria were explained to all participants. An explanation was given to the participants that were excluded as to why they won't be able to partake. It was explained to them that scientific research is aimed at giving accurate results for a set patient profile and that it is important to exclude variables that could affect the results. The participant was informed that they will still be able to receive the final results of the study. If the excluded participant insisted that they wanted to partake in testing, the motion analysis test was offered to them. This test was then not used in any data analysis.

3.4 Instrumentation and Outcome Measures

Variables were tested in order to identify differences and similarities between the two groups (see Table 3.2).

Table 3. 2 Outcome Measures and Instrumentation

Variables	Instrumentation and Tools used	Reliability
Demographic data; history and behaviour	Electronic self-report questionnaire	(Fontecha *et al.*, 2011)
Active range of motion: lumbar flexion, extension, lateral flexion, rotation; and hip internal and external rotation	Standard goniometer and inclinometer smartphone app	ICC of ≥ 0.86 (Kolber *et al.*, 2013). ICC 0.82 to 0.90 (Nussbaumer, 1997)
Dynamic lower limb balance	Star Excursion Balance Test (SEBT)	ICC of 0.86 to 0.92 (Gribble *et al.*, 2013)
Kinematics of the trunk and hips: flexion-extension, abduction-adduction and internal-external rotation motions during the tennis serve	Inertial measurement unit system: Xsens MVN inertial motion capture system and Xsens MVN Studio software	ICC of 0.60 to 0.95 (Al-Amri *et al.*, 2018)
Muscle activation during the tennis serve of the rectus abdominis, external obliques, erector spinae and gluteus maximus muscles	Surface electromyography (EMG): Delsys Trigno eight wireless EMG sensors and Delsys EMGworks software	ICC of 0.60 to 0.90 (Bandpei *et al.*, 2014)

3.4.1 Self-report Questionnaire

It has been reported that self-report questionnaires can be used reliably in adolescents older than eleven years (Fontecha *et al.*, 2011). Safran and Kibler (2005) developed a questionnaire for tennis players that have been shown to be both valid and reliable. The questionnaire consisted of five parts: identification data, history of playing, training history, equipment history and history of injury.

For the purpose of this study, Safran`s questionnaire was used as a guideline to create a self-report questionnaire (See Appendix I). The questionnaire was made available to the players in English and Afrikaans. It was translated by the main researcher and a language editor. Both questionnaires were reviewed by a panel of experts, including an experienced researcher, an adolescent and a language editor, to ensure content validity. The test-retest reliability of the questionnaire was assessed on two separate occasions, five days apart. No changes were necessary after the test-retest procedure had been conducted.

The questionnaire was completed by participants through the use of an electronic survey system. Data were collected and managed using an electronic data capture tool hosted at the University of the Witwatersrand (Harris *et al.*, 2008). REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies. It provides for: (1) an intuitive interface for validated data entry; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; (4) and procedures for importing data from external sources.

3.4.2 Active Range of Motion Testing

Active ROM testing was done by using either a standard goniometer or an inclinometer smartphone application (app). The standard goniometer (Hitech Therapy, Johannesburg, South Africa) is made of transparent plastic and provides a clear view of the joint axis and ROM. The Clinometer app, version 4.6 on iOS, is produced by Plaincode App Developer (Plaincode, Stephanskirchen, Germany).

Measuring ROM with a standard goniometer has acceptable intra-rater and interrater reliability (Ekstrand *et al.*, 1982; Nussbaumer, 1997; Hjelm, Werner and Renstrom, 2012; Schlager *et al.*, 2018). However, the importance of a standardised procedure in order to minimise error during the testing procedure is recommended (Schlager *et al.*, 2018). Inclinometer apps have demonstrated good intra-rater and interrater reliability, as well as concurrent validity, when compared to the bubble inclinometer used in lumbar mobility (ICC ≥ 0.86) (Kolber *et al.*, 2013). Easy accessibility and efficiency make this method of testing ROM a good option (Kolber *et al.*, 2013; Smith, 2016).

Prior to each test, the participant was instructed as to how to do the movement, which was also demonstrated. Standardised verbal cues were used to ensure proper form and end of ROM. A skin marker was used to place a reference point on the landmark needed during the testing procedure.

Active ROM was tested with the inclinometer smartphone app in the standing position for thoracolumbar flexion, thoracolumbar extension, left lateral flexion and right lateral flexion. The following methods were used by Kolber *et al.* (2013) for calculating the thoracolumbar ROM:

- The iPhone is placed with the power button side on the respective T12/L1 and the L5/S1 intervertebral spaces in order to test total thoracolumbar flexion. The starting angle is recorded and added to the final angle recorded at that level during the flexion motion. The results are then subtracted (L5/S1 from T12/L1) in order to provide an isolated lumbar flexion value.

- During the measurement of thoracolumbar extension, the port connection side of the iPhone is placed at T12/L1. Again, the starting angle and the end-of-range angle are recorded and then subtracted (L5/S1 from T12/L1).
- Finally, to determine thoracolumbar lateral flexion value, the iPhone is placed flat at the T9 to T12 levels. The iPhone is zeroed prior to movement and the end-of-range value is recorded (Kolber *et al.*, 2013).

Hip rotation and the thoracolumbar rotation active ROM were tested with a standard goniometer. Testing was done with the participant sitting on a wooden chair with the hips flexed at a 90° angle.

- For the hip rotation ROM testing, the participant was instructed to keep the pelvis stationary on the chair, whilst rotating the hip and moving the foot inward (external rotation of the hip) and/or outward (internal rotation of the hip).
- In order to test thoracolumbar rotation, a standard pole resting on the shoulders and held by both hands were used (Hjelm, Werner and Renstrom, 2012). The participant was instructed to perform the motion by rotating around one central point and not bending forwards or backwards. The examiner monitored and assisted the participant to refrain from using pelvic tilt or any other auxiliary movement that could affect the test measurements.

3.4.3 Star Excursion Balance Test

The SEBT has been widely tested for functional validity as a screening tool for lower quarter musculoskeletal injuries (Kinzey and Armstrong, 1998; Hertel *et al.*, 2006; Gribble, Hertel

and Denegar, 2007; Robinson and Gribble, 2008; Endo and Sakamoto, 2014; Ganesh, Chhabra and Mrityunjay, 2015). Good inter-rater reliability has been shown in this tool with an ICC of 0.86 to 0.92 for normalised distances (Gribble *et al.*, 2013). The tests for reaching in the anterior, posteromedial, and posterolateral directions (Y-Balance Test), have also gained excellent intra-rater and interrater reliability results, whether the chosen outcome be the average or maximum score using raw or normalised data (Gribble *et al.*, 2013).

In a comparative study, as opposed to the performance of the participants in the Y-Balance Test, healthy participants achieved a longer reach distance in the anterior direction of the SEBT (Coughlan *et al.*, 2012). In fact, Endo and Sakamoto (2014) observed a significant correlation in the SEBT between lower extremity muscle tightness (including the internal hip rotators, hamstring and gastrocnemius) and the reach direction in junior high school baseball players (Endo and Sakamoto, 2014). It was hypothesised that the same muscle tightness could be present in adolescent tennis players.

The test is performed in the centre of a grid with eight lines that cross at an angle of 45°. The participant is asked to stand on one leg in the centre of the grid and to reach out with the other foot and lightly touch each line. The participant then moves his/her leg back to the middle of the grid. The distance is measured from the centre of the “star” to the point reached on the gridline.

The reach is defined according to the weight-bearing leg and the direction of movement (e.g. right leg for weight bearing and the left leg for anteromedial reach will be termed right anteromedial reach). Directions of movement include the following: right anteromedial, left

anteromedial, right anterior, left anterior, right anterolateral, left anterolateral, right lateral, left lateral, right posterolateral, left posterolateral, right posterior, left posterior, right posteromedial, left posteromedial and medial directions. It was decided for the purpose of this study that the medial reach directions would not be included as a testing procedure as some of the younger adolescent participants consistently struggled to reach in this direction. The medial reach direction has not been cited in research as significant (Shaffer *et al.*, 2013).

The participants received three practice trials and were asked whether they felt comfortable to commence the test. The test was performed by starting with the right leg as the weight-bearing leg; then moving to the left leg as the weight-bearing leg. A five-second rest was given between the tests for each leg. The SEBT was repeated three times for each leg. The reach distance was measured in centimetres using a standard measuring tape. Normalisation was then performed in order to view the distance as a percentage in relation to the participant's leg length (Gribble, Hertel and Denegar, 2007). Leg length was measured from the anterior superior iliac spine (ASIS) to the distal tip of the medial malleolus. Reach distances were normalised to limb length by calculating the maximised reach distance (%MAXD) using the formula (excursion distance/limb length) x 100 = % MAXD. This normalisation method accounts for limb length differences in individuals and allows for comparisons between the right and left limbs and between participants (Coughlan *et al.*, 2012).

3.4.4 Three-dimensional Motion Analysis: Kinematics

Inertial Measurement Unit (IMU) motion-capture systems are portable and less expensive than traditional camera-based motion-capture systems (Al-Amri *et al.*, 2018). It is possible

to use an IMU system outdoors (for example on a tennis court) and not be confined to a closed laboratory setting. IMU systems have shown that they are reliable and produce valid results when comparing a qualified physiotherapist, inexperience with an IMU system, to a clinical movement scientist, trained in the IMU system (Al-Amri *et al.*, 2018).

The Xsens MVN IMU motion capture system (Xsens Technologies B.V., Enschede, the Netherlands) was used to evaluate the kinetic motion of the trunk and hips during the tennis serve. This Xsens MVN system is a full-body inertial kinematic measurement system incorporating synchronised video data. It provides instant graphical output, including joint angles (Xsens Technologies, 2018). The system comprises of 17 motion trackers that measure 21 joint centres, with the final tracker being placed on a prop, for example, a tennis racquet. The motion trackers are placed on top of the joints in the Xsens MVN motion-capture suit, which is made of lycra material and has multiple pockets in which the trackers are placed. It is designed to ensure good fixation to the body and to minimise the skin-artefact motion (Xsens Technologies, 2018). To further ensure that the motion tracker remained fixed on the body part, straps were used to fix the tracker onto the younger and/or smaller participants.

In a study conducted by Seel *et al*. (2014), the IMU-based method was compared to an optical 3D motion-capture system for gait analysis. These researchers found the root mean square errors of knee flexion/extension angles to be less than one degree (1º) on a prosthesis, and approximately three degrees (3º) on the human leg (Seel, Raisch and Schauer, 2014). The difference in error on the human leg was explained to be due to the soft tissue of the leg. This indicates firstly that the IMU system is comparable to other

systems currently used in research; and secondly, the importance of correct placement procedures of the motion trackers to minimise the margin of error.

Before the commencement of this study, the main researcher received training from an Xsens MVN IMU motion-capture systems representative on the correct placement of motion trackers. Trackers were placed by palpating anatomical landmarks, avoiding soft tissue bulk, and using the guidelines on the Xsens body suit (Xsens Technologies, 2018).

A fundamental problem in IMU-based human motion analyses is that the local coordinate axes of the IMUs are not aligned with the physiological joint axes (Seel, Raisch and Schauer, 2014). However, the Xsens MVN system makes use of “neutral” calibration poses (termed the N-pose or T-pose) to identify sensor-to-segment orientations and, thus, the coordinates of the joint axes (see Figure 3.1). The algorithm uses a biomechanical model and kinematic constraints to overcome integration drift (Roetenberg, Luinge and Slycke, 2013).

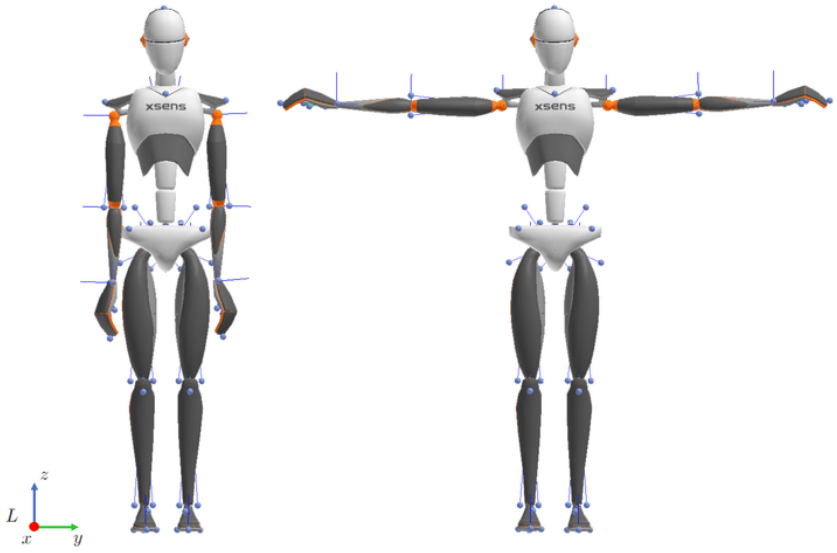


Figure 3. 1 The N-pose and T-pose for neutral calibration of the MVN Xsens software (Xsens Technologies, 2018)

Prior to commencing the kinetic motion analysis recording, the participant was asked to stand in a static N-pose for approximately 30 seconds. A tutorial video of the N-pose and calibration can be accessed on the Xsens website and is also explained in the user manual (Xsens Technologies, 2018). Since the accuracy of the system is determined by the precision with which the participant can adopt and maintain the correct posture, the calibration pose was considered to be extremely important (Seel, Raisch and Schauer, 2014). Thus, if the adolescent participant were to struggle to maintain the N-pose, he/she would be given assistance in finding the correct position and posture. In some cases, assistance was given to hold the racquet straight or to find the correct shoulder-pelvis orientation.

3.4.5 Muscle Activation Analysis: Electromyography

The eight-wireless EMG sensors from Delsys Trigno were used to capture muscle activation levels during the tennis serve (Delsys Inc., Salford, Greater Manchester, United Kingdom). The Delsys Trigno sensor is a high-performing device designed to make the detection of the EMG signals reliable and easy. The system is capable of streaming data digitally into EMGworks software, or third-party software, or via analogue channels for integration into motion capture and other third-party data-acquisition systems (Delsys Inc., 2014).

Surface electromyography (sEMG) is commonly used to quantify the magnitude and timing of muscle activation during various physical tasks (Worrell, Crisp and LaRosa, 1998; Fauth *et al.*, 2010). A systematic review reports that the sEMG can be considered to be a useful and reliable tool to evaluate paraspinal muscle fatigue in healthy participants and in patients with lower back pain (Bandpei *et al.*, 2014). Fauth *et al*. (2010) reported sEMG in the lower limb, as a reliable method to assess the activation of the quadriceps and hamstring muscles

during either MVIC, slow dynamic, or ballistic movements. Wireless sEMG has also been used in the detection of muscle fatigue in the case of the vastus lateralis muscle during an exercise task (Chang, Liu and Wu, 2012). However, consensus was not reached in a systematic review as to how to measure and analyse the detection of muscle fatigue in sEMG data produced during running activities (Subbu, Weiler and Whyte, 2015).

In tennis players, EMG studies have often investigated the rotator-cuff and forearm musculature during strokes (Ellenbecker *et al.*, 2009; Abrams, Renstrom and Safran, 2012). One study has found sEMG to be successful in the testing of endurance and trunk muscle activation during static postures for tennis players with and without lower back pain (Correia *et al.*, 2016). The use of sEMG has also been shown to be valid and reliable when assessing neuromuscular responses in abdominal muscles during functional tasks (Marshall and Murphy, 2003). Through the literature, it can be seen that although consensus has not yet been reached on the issue as for how to measure and analyse sEMG during running, the sEMG has been used widely to test MVIC, slow dynamic tasks and functional movements.

In contrast to fine-wire electromyography (fEMG), sEMG measures the electrical activity of the chosen muscle from the surface of the skin, and without the use of a fine wire that needs to be inserted intra-muscularly. Owing to the functional nature of testing and considering the fact that we were working with adolescents, sEMG was the obvious choice for this study. The sEMG sensor needs to be applied on the surface of the skin above the muscle of interest (Chang, Liu and Wu, 2012). Surface electrodes were therefore placed on the left and right RA, EO, ES, and GM muscles (see Table 3.3).

Sensor placement and skin preparation were carried out according to the specifications of the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) project (www.seniam.org). The skin was prepared before testing by shaving and cleaning it with alcohol wipes. Sensors were applied to the area with the greatest muscle bulk and in the direction of the muscle fibres. The researcher also made sure that the sensor would continuously remain over the chosen muscle during movement. (The placement of the sensors and the testing procedure are summarised in Table 3.3. – (Table developed from Worrell, Crisp and LaRosa, 1998; Lim, Chow and Chae, 2012; Correia *et al.*, 2016).

MVIC was required in order to normalise the EMG data for each participant. The maximum contraction of the muscle tested was held for five seconds and repeated three times in order to obtain an accurate activation pattern. Participants were encouraged to give their maximum voluntary contraction. Each participant rested for one minute after each MVIC to eliminate muscle fatigue.

Table 3. 3 Placement of EMG Sensors and Testing Procedure (authors own work)

Muscle:	sEMG sensor placement:	MVIC Testing Procedure:	Hand Placement:
RA	3cm lateral to the umbilicus	Supine position with knees bent and feet flat on the floor. Trunk inclined at approximately 30° from the horizontal. Resist isometric trunk flexion.	Person 1: hold shoulders Person 2: hold knees/feet
EO	15cm lateral to the umbilicus	Supine position with knees bent and feet flat on the floor. Trunk inclined at approximately 30° from the horizontal and rotated toward the tested side. Resist isometric trunk rotation.	Person 1: hold shoulders Person 2: hold knees/feet

ES	3cm lateral to the L4 spinous process	Prone position with arms at sides. Trunk lifted into extension. Resist isometric trunk hyperextension.	Person 1: hold posterior trunk Person 2: hold lower limb
GM	1/3rd of the distance from the second sacral vertebrae to the greater trochanter	Prone position with hip at 0° (neutral). Bend knee to approximately 90° of flexion and extend hip. Resist isometric hip hyperextension.	Person 1: hold knee/hip Person 2: hold posterior trunk

sEMG – wireless surface electromyography; MVIC – maximum voluntary isometric contraction; RA – rectus abdominis; EO – external obliques; ES – erector spinae; GM – gluteus maximus

3.5 Procedure

3.5.1 Pilot Study

A pilot study was conducted to establish the time it takes to complete all physical testing measurements and to identify any problems which might arise during the data collection process. The pilot study was carried out on six participants – 12.77% of the total sample size (total=47). No major changes were required after the pilot study. The results pertaining to the participants who took part in the pilot study were included in the main body of the research data.

3.5.2 Main Study

Tennis players from the North Gauteng Tennis Club were invited via email and telephonic communication to participate in this study. Participants who responded and were accepted received a link to the self-report questionnaire. The self-report questionnaire was completed by the participants at home and in their own time. The tennis player and parents were

synchronously contacted and a date was scheduled for data collection that would suit the tennis club, tennis player and researcher.

On the day of data collection, an information sheet and consent forms were presented to the parents and tennis players. The procedure for the day was explained. During the introduction, it was explained that participation was voluntary and that the participant could leave the study at any point. The procedure for the day was set up in phases (see Figure 3.2). At this point, it was also explained to the participant that the researcher and assistants would need to know only the participant's allocated number and no further details from the questionnaire. The researcher, therefore, did not know which of the players had back pain and which did not. This eliminated bias in the data collection process.

The researcher was responsible for obtaining informed consent, body and ROM measurements, application and removal of the EMG sensors and IMU trackers, and further data collection. The research assistant aided the researcher in writing down measurements, application and removal of the IMU trackers, and aided in further data collection.

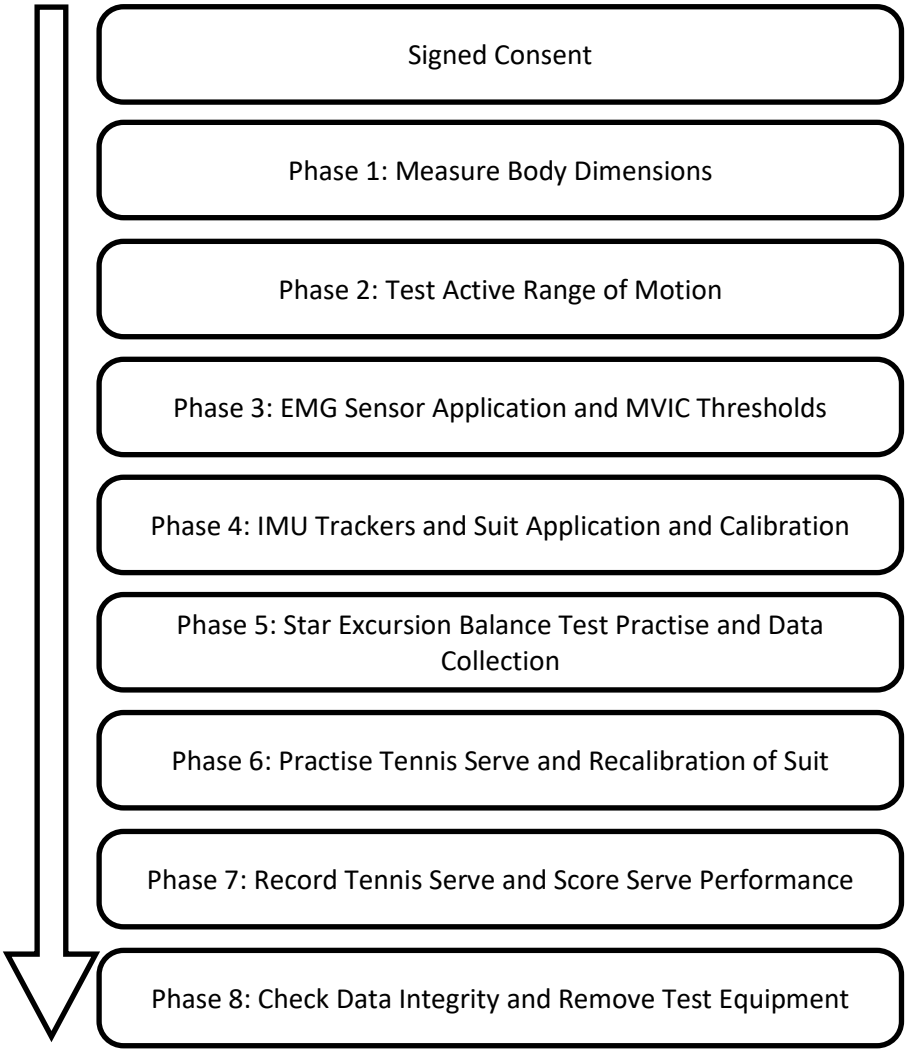


Figure 3. 2 Data Collection Testing Procedure (authors own work)

EMG – electromyography; MVIC – maximum voluntary isometric contraction; IMU – inertial measurement unit

A five-minute warm-up was performed in order to establish the same baseline for muscle activity. The warm-up included ten repetitions of marching on the spot, upper limb circles and squats. Data collection was completed on the tennis court. The participant's weight (kg) and body dimensions (in cm) were measured in phase one to enter into the Xsens MVN Studio software prior to data collection. Body dimensions included head to toe (cm), heel to toe, finger to finger, floor to medial malleolus, floor to greater trochanter, ASIS to ASIS, floor to lateral epicondyle of the knee, left to right acromion, and the inner sole height of the middle foot. Leg length was also measured to calculate the normalisation of the SEBT at a later

stage. This was followed by active ROM testing of the lumbar spine and hip rotations in phase two. The active ROM, SEBT and Xsens MVN body dimension measurements were recorded on a data sheet (see Appendix II).

Phases 3 and 4 each constituted a crucial leg in the data collection process (see Figure 3.2). Before commencement of the set-up and the recording of the tennis serve, the Delsys Trigno eight wireless EMG sensors were applied under the Xsens MVN suit and MVIC testing was done. [The set-up and recording procedure of sEMG data are explained in Table 3.4, while the procedure for the motion-analysis data-collection process using the Xsens MVN Studio software is set out in Table 3.5.] Both the EMG sensors and the IMU trackers were applied with precision in order to accurately record data.

Table 3. 4 Set up and Recording of the Tennis Serve using the Delsys Trigno sEMG System (authors own work)

Procedure for the Delsys Trigno sEMG System
1. Preparation and marking of the skin for placement of sEMG sensors
2. Application of sEMG sensors
3. Activation of Delsys EMGworks software and the loading of the participant on the system
4. Capturing of MVIC data (three repetitions; five-second contractions; one-minute rest)
5. Set-up of Xsens MVN system
6. Synchronisation of Xsens MVN Studio software and Delsys EMGworks software
7. Recording of data (six tennis serves)

sEMG – wireless surface electromyography; MVIC – maximum voluntary isometric contraction.

Table 3. 5 Set up and Recording of the Tennis Serve using the Xsens MVN System (authors own work)

Procedure for the Xsens MVN system
1. Measurement of body dimensions
2. Getting dressed in the suit
3. Attachment of motion trackers to suit
4. Practising six tennis serves
5. Adding body dimensions to Xsens MVN Studio software
6. Synchronisation of Xsens MVN Studio software and Delsys EMGworks software
7. Calibration in the N-pose
8. Checking magnetic field and quality of calibration
9. Recording of data (six tennis serves)

The participant was requested to perform six practice runs of the serve before the data were collected. The researcher asked participants whether they felt comfortable and ready before commencing with the data recording process. Testing was done on a hard surface tennis court, using the tennis player's personal exercise gear and racquet. A set of tennis balls was newly acquired specifically for this study. Participants were asked to perform the serve that they would use first during a competition and hit the ball "down the tee". All participants reported using the flat serve. As can be seen in Figure 3.2 – phase 7, after each tennis serve, the participant was asked to give a score out of five for the performance of the serve – "how it felt" to them. Data pertaining to the SEBT and the tennis serve were collected in subsequent phases. During these testing procedures, video footage was taken to assist with the interpretation of the data and test results.

3.6 Ethical Considerations

Ethical clearance was obtained from the medical division of the Human Research Ethics Committee of the University of the Witwatersrand before commencement of the study (Ethical Clearance no: M161121, Appendix III). Parents or legal guardians were asked to sign for informed consent and complete an indemnity form from the university in order for the tennis player to participate in this study (see Appendices IV, V and VI). The tennis player was asked to sign for informed assent to participate (see Appendices IV and V).

Informed consent and assent included the following aspects:

(1) description and purpose of the study;

(2) expectations of the tennis player concerning the study;

(3) inclusion and exclusion criteria and confidentiality;

(4) an explanation of informed consent directed at the tennis player and guardian;

(5) consent to take video footage;

(6) and lastly, the contact details of the principal researcher – which were provided in case the parents required more details.

For the self-report questionnaire, electronic consent was obtained (“click for consent”). Written consent was obtained on the day of the data collection process.

Each questionnaire was allocated a number to uphold anonymity. The student was filmed from behind, with no identifying features. Photos were taken only if informed consent had been obtained. Data pertaining to the participant were collected and inserted on a spreadsheet, with an allocated number to uphold anonymity. At no point in time were the participant`s personal particulars and data associated with one another. All data were saved

on a computer-encrypted hard drive and password-protected. Electronic and hard-copy information was kept safe by the principal researcher.

The well-being of the participants was of utmost importance. Appropriate measures were taken to keep participants safe from injury, as far as possible. These included: carrying out the data collection process in proper lighting and under good weather conditions, using home courts with which the participants were familiar, and using their own equipment (racquet, shoes, etc.). Exclusion criteria determined who was not able to participate and thus also assisted in the safekeeping of the participants.

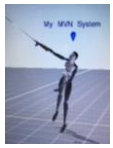
The examination was in no way different from their usual or normal exercises, training and/or ability to move. All participants had the option to withdraw at any time without suffering any repercussions. No participants were injured or withdrew during testing. Information obtained from participants was used only for the purpose intended for this study. The results of this study will be made available to all participants via publication.

3.7 Data Processing and Reduction

Before the analysis process, the data had to be processed and reduced for the SEBT, the motion analysis and the EMG findings. As discussed in the instrumentation section, the SEBT data were normalised according to the participant's leg length in order to calculate the %MAXD. Raw EMG data were treated with a Butterworth filter and normalised to the participant's MVIC. The EMG results were presented as a root mean square and expressed as the %MVIC.

In order to analyse the kinematics and muscle activation data of each participant during the tennis serve, markers were identified by means of the Xsens MVN Studio software. There was six tennis serves recorded for each participant, with seven markers being placed on each serve attempt. The data were converted from the Xsens MVN Studio software to an mvnx file, which could be opened in Excel for data cleaning and extrapolation purposes. As a result of the synchronisation of the Xsens MVN Studio software and the Delsys Trigno software during data collection, the same point in time was used for the motion analysis and the EMG data. The details of the seven markers that were set to identify phases in the tennis serve are explained in Table 3.6. The markers included the starting point, point of ball release, maximum loading point, maximum cocking point, point of ball contact, maximum shoulder abduction, and the finish point of the serve.

Table 3. 6 Description of Marker Placement for Phases of the Tennis Serve on MVN Studio Software (authors own work)

Marker	Phase of Tennis Serve	Phases of Tennis Serve	Explanation of Where Marker was Placed	
PS	Preparation Phase	Starting Point	Maximum elbow flexion in non-racquet arm, matched with elbow flexion in racquet arm	
PR	Preparation Phase	Point-of-Ball Release	Release of ball in video footage matched with axis of wrist flexion	
PL	Preparation Phase	Maximum Loading Point	Maximum flexion in racquet-side knee matched with flexion in non-racquet-side knee	
PC	Preparation Phase	Maximum Cocking Point	Racquet position closest to 0° on the x-axis, matched with maximum shoulder external rotation in racquet arm	
AC1	Acceleration Phase	Point of Ball Contact	Racquet acceleration, point of vibration on graph (ball contact)	
AC2	Acceleration Phase	Maximum Shoulder Abduction during Ball Contact	Maximum shoulder abduction in racquet arm, matched with point of vibration (ball contact)	
DF	Deceleration Phase	Finish Point of Serve	Maximum dorsiflexion in racquet side ankle, matched with maximum dorsiflexion in non-racquet-side ankle	

PS – preparation phase, starting point; PR – preparation phase, point of ball release; PL – preparation phase, maximum loading point; PC – preparation phase, maximum cocking point; AC1 – acceleration phase, point of ball contact; AC2 – acceleration phase, maximum shoulder abduction during ball contact; DF – deceleration phase, finish point of serve

The start, ball release, loading, cocking, ball contact and finish points have all been used in other studies to explain the specific points and phases of the serve (Chow, Shim and Lim, 2003; Kovacs and Ellenbecker, 2011c; Campbell *et al.*, 2013; Correia *et al.*, 2016). During the acceleration phase, the mean shoulder abduction before ball contact is approximately 100° (Kovacs and Ellenbecker, 2011c). The researcher hypothesised that maximum shoulder abduction would occur directly after or before the point of ball contact. At maximum shoulder abduction, the biomechanical chain from the shoulder down to the hip is in a "stretched" position. The cocking phase can be seen as the point of maximum compression in the lower quarter. Hence, the phase of maximum shoulder abduction can be regarded as the point of maximum distraction.

The Xsens MVN Studio software makes use of the coordinate system to calculate joint angles. For example, the flexion-extension of the hip is described by the rotation about the ^{B}Z-axis (sagittal plane) of the upper leg with respect to the pelvis; abduction-adduction is the rotation about the ^{B}X-axis (frontal plane); and internal-external rotation is about the ^{B}Y-axis (transverse plane) (Xsens Technologies, 2018). Issuing from the processing and interpretation of the results for the ^{B}Z-axis, flexion was recorded as positive (+ve) and extension as negative (-ve). The ^{B}X-axis displayed abduction (+ve) and adduction (-ve). Lastly, the ^{B}Y-axis displayed internal rotation (+ve) and external rotation (-ve) (Olivier *et al.*, 2018). In the spine, abduction displayed lateral flexion towards the racquet arm (to the right), and adduction displayed lateral flexion away from the racquet arm (to the left). Internal rotation displayed rotation away from the racquet arm (to the left), whilst external rotation displayed rotation toward the racquet arm (to the right).

The presence of lower back pain was used as the grouping variable. Data (active ROM, SEBT, kinematics and muscle activity) for each participant was analysed in terms of dominant/non-dominant sides and not in terms of left and right. For the analysis of the active ROM, motion analysis and EMG, the left-handed players' data were reversed in order to analyse the data in terms of upper limb dominance. Data for a participant with a dominant left lower limb were reversed so that the data for the SEBT could be analysed in terms of lower limb dominance. All results should, however, be interpreted as if the participants were right dominant.

3.8 Data Analysis

Each participant gave a score out of five for their performance in executing six tennis serves. The performance rating was analysed to measure whether the two groups were matched in terms of execution. The rating is used as a subjective measure of the participant's confidence in the execution of their serve. For each participant (n=33), all six tennis serves were entered into the analysis and the total was analysed collectively (n=198). The same procedure was done for the SEBT results (three reaches for each leg) (n=99).

IBM SPSS version 25 software was used for the data analysis. Lower back pain status was used as the dependent variable. Means and standard deviations were used to describe the demographic history and the point of maximum muscle activity. Medians and ranges were used to present active ROM, SEBT, kinematics and muscle activation levels. Testing was seen to be statistically significant for $p < 0.05$. Owing to the relatively unbalanced sample sizes between the LBP (n=12) and NLBP (n=21) groups, non-parametric measures were used to investigate the differences that might exist between these groups. The Chi-Square

(X^2) test was used to look at the differences between the categorical variables. Furthermore, a Mann-Whitney U test was used to determine the statistically significant differences between the independent variables.

All data were critically investigated in order to identify the specific movements and muscle activations of the two groups. Differences between the two groups, as well as significant aspects in the differences, were explicated in the interpretation of results.

Significant kinematic and muscle activation findings from the above-mentioned tests were used for further analysis. A Pearson bivariate correlation analysis was performed to determine the relationships that exist between these variables. Results were interpreted by means of the following value descriptions: perfect negative downslope linear relationship (r=-1.00), strong negative downslope linear relationship (r=-0.70), moderate negative downslope linear relationship (r=-0.50), weak negative downslope linear relationship (r=-0.30), no linear relationship (r=0.00), weak positive upslope linear relationship (r=0.30), moderate positive upslope linear relationship (r=0.50), strong positive upslope linear relationship (r=0.70), perfect positive upslope linear relationship (r=1.00).

The primary reason for the correlation analysis was to investigate the issue of co-linearity between variables for further analyses using regression methods. A binary logistic regression model was used to determine which of the variables found in the correlation was the strongest at predicting whether a participant would be categorised into the LBP or NLBP group.

The Forward Stepwise (Wald) method was used. Statistically insignificant values (i.e. those with no co-linearity) demonstrated a good fit in the Hosmer-Lemeshow test. Variation in group classification was assessed with the Cox and Snell R-square and the Nagelkerke R-square tests. In the logistic regression model, the regression heights coefficient was presented as (B). Furthermore, the change in odds was calculated as a percentage using the following equation: Exp(B) x 100 – 100 = OR%. The odds ratio (OR) is a presentation of variables in the regression model and can be explained as a percentage increase for every one unit of one variable that is concomitant with an increase/decrease in another associated variable.

3.8 Conclusion of Methodology

The presence of lower back pain can never have a single causative factor. Correspondingly, there are multiple potential risk factors for injury of the lower back. The researcher decided on the variables that were chosen and explained in the methodology after a comprehensive study of the relevant literature. The motivation behind the variables chosen includes the fact that the statistical significance of these variables and their group classifications could conceivably be an indication of probable constructs to include in injury-prevention programmes.

CHAPTER 4: RESULTS

4.1 Introduction

The results chapter has been divided into eight subsections. The demographic data are discussed in the self-report questionnaire section. This is followed by a report on the physical testing of the active ROM and SEBT, which is discussed in Sections three and four. Section five deals with the trunk and hip kinematics during the serve. In the sixth and seventh sections, various aspects of muscle activity are discussed. Section eight presents the correlations between the tested variables, and Section nine the logistic regression analysis of significant variables.

4.2 Participants

Forty-seven (47) adolescent tennis players from the North Gauteng Tennis Club volunteered to participate in this study. Forty-two (42) tennis players met the inclusion and exclusion criteria. Five participants were excluded for the following reasons: metabolic condition (type-A diabetes with an insulin pump), diagnosed acute spondylolisthesis, other musculoskeletal injuries (one ankle and one knee) and lack of experience (less than three years). The data for nine participants were disregarded owing to a problem with the synchronisation of the Xsens MVN Studio software and the Delsys EMGworks software on the day of testing. A total of 33 participants completed all the outcome measures of the study and were included in the final sample (see Table 4.1). The final sample comprised of 21 in the NLBP group and 12 in the LBP group.

Table 4. 1 Demographic Information for the Final Sample (n=33) of Participants

		Group			
		NLBP (n=21)		LBP (n=12)	
		n	%	n	%
Sex	Male	17	81.00%	7	58.30%
	Female	4	19.00%	5	41.20%
Lower Back Pain in the last Month	No	21	100.00%	4	33.30%
	Yes	0	0.00%	8	66.70%
Lower Back Pain in the last six Months	No	21	100.00%	2	16.70%
	Yes	0	0.00%	10	83.30%
Dominant Upper Limb	Left	2	9.50%	1	8.30%
	Right	19	90.50%	11	91.70%
Dominant Lower Limb	Left	2	9.50%	5	41.70%
	Right	19	90.50%	7	58.30%
Experience (years)	> 5 years	15	71.40%	10	83.30%
	> 3 years, < 5 years	6	28.60%	2	16.70%

NLBP – participants without lower back pain; LBP – participants with lower back pain

Demographic data was analysed from the self-report questionnaire (Table 4.1). Twenty-one participants were accepted in the NLBP group and 12 in the LBP group (eight with LBP in the last month, and ten with LBP in the past six months). No significant association between sex and group classification was found (NLBP: 17 males; four females; LBP: seven males; five females; p=0.230). There was no association between upper limb dominance and group classification in the two groups (p=0.909). The majority of the participants were dominant in their right upper limb (30 right-side dominant; three left-side dominant). A significant

association was found between lower limb dominance and group classification (p=0.015). The LBP group had more left lower limb dominant tennis players (NLBP: two left; 19 right; LBP: five left; seven right).

For the LBP group, an average pain level of 3.38/10 on the Visual Analogue Scale (VAS) was reported in the past month, and a VAS of 5.33/10 over the previous six months (see Figure 4.1). The majority of the LBP group indicated that they had experienced the onset of back pain during a tennis training session or tournament. Four participants in the LBP group (n=12) had to stop practice or play in the previous six months on account of back pain. None of the participants reported an acute onset of back pain during the week of the testing procedure. This indicated that none of the participants were influenced by acute back pain during the testing procedure.

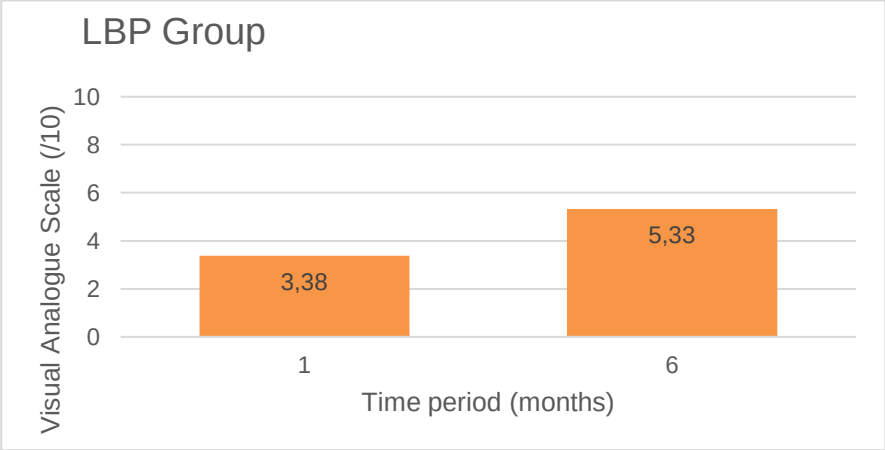


Figure 4. 1 Pain Scale for the LBP Group (n=12) in the Last Month and in the Last Six Months

LBP – participants with lower back pain

The mean age of participants was between 13 and 14 years for both groups (NLBP: 13.43±2.20; LBP: 14.92±1.98; p=0.062), see Table 4.2. The mean age when starting to play tennis was seven years old (NLBP: 7.14±2.41; LBP: 7.00±2.66; p=0.876). Even though the

LBP group (58.7±45.8kg; minimum 31.4kg) weighed more than the NLBP group (49.6±39.9kg; minimum 26.1kg), there was no difference between the body mass index (BMI) of the two groups (NLBP: 19.65±2.79; LBP: 21.11±2.47; p=0.142), as can be seen in Table 4.2. There were no significant differences in the height of the participants between the two groups (NLBP: 1.59±0.13m; LBP: 1.66±0.17m; p=0.168).

Table 4. 2 Demographic and Subjective History of the NLBP and LBP Groups

	Group				p
	NLBP (n=21)		LBP (n=12)		
	Mean	Std Dev	Mean	Std Dev	
Age (years)	13.43	2.20	14.92	1.98	0.062
Height (m)	1.59	0.13	1.66	0.17	0.168
BMI (kg/m2)	19.65	2.79	21.11	2.47	0.142
Age when started to play tennis (years)	7.14	2.41	7.00	2.66	0.876
Use of the topspin serve type (%)	33.81	34.71	35.83	30.29	0.867
Use of the flat serve type (%)	50.00	34.21	56.67	29.02	0.574
Use of the slice serve type (%)	16.19	32.01	7.50	9.65	0.369
Play on hard court (hr/p/w)	5.86	2.59	8.08	3.73	0.052
Practise tennis (hr/p/w)	5.71	2.69	7.75	4.27	0.102
Play doubles (hr/p/w)	1.21	0.68	1.42	1.00	0.494
Play singles (hr/p/w)	2.10	1.22	2.00	0.85	0.813
Play other sports (hr/p/w)	3.48	2.89	1.42	2.39	0.045
Exercises/Stretches (hr/p/w)	1.79	1.22	2.42	2.81	0.376
Training (hr/p/w)	5	8	8.5	12	0.118

NLBP – participants without lower back pain; LBP – participants with lower back pain; Std Dev – standard deviation; BMI – body mass index; hr/p/w – hours per week. Grass and clay courts had limited entries – not viable for analysis

All of the participants in the NLBP and LBP groups reported regular use of the flat serve. Fifty-seven percent (57%) of the LBP group, and 50% of the NLBP group reported the use of the flat serve for the majority of their service motions (NLBP: 50±34.21%; LBP: 56.67±29.02%; p=0.574). Participants reported that the flat serve was used mostly for the

first serve and the topspin mainly for the second serve. Figure 4.2 illustrates the percentage of each serve type during a tennis match for the two groups.

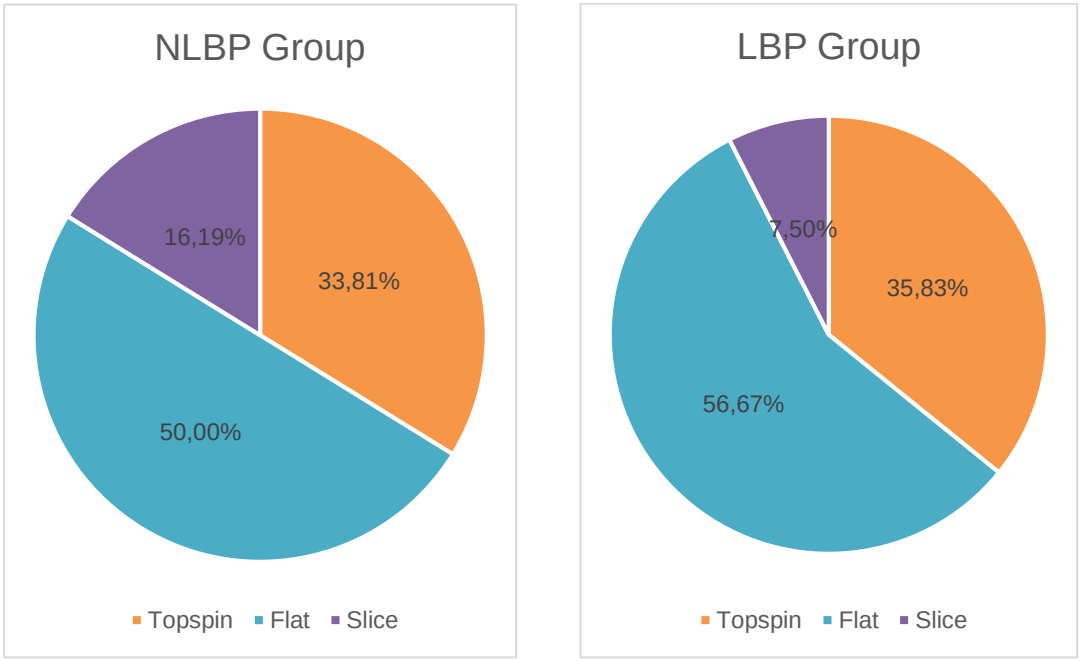


Figure 4. 2 Type of Serve used in a Game for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain

Furthermore, according to Table 4.2, all participants reported play on a hard-court surface, with an average of 5.86±2.59 hrs (NLBP group) and 8.08±3.73 hrs (LBP group) spent on the court per week. This indicates a significant association between the number of hours played on a hard-court surface and the presence of LBP (p=0.052). There was no difference between the two groups when the number of hours played on a grass-court (p=0.443 for the two groups), or a clay-court (p=0.523 for the two groups) surface, during training or playing, were considered.

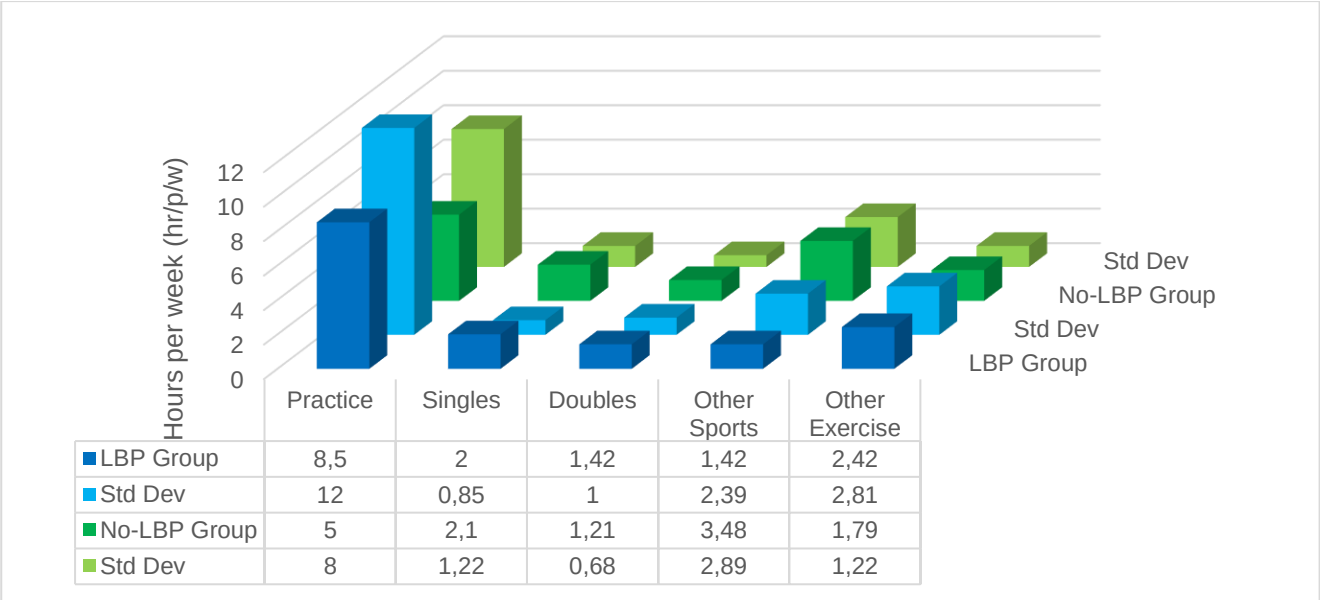
Table 4.2 shows that, compared to the LBP group, the NLBP group spent significantly more time playing other types of sport (p=0.045). On considering participation in other sport types,

71.43% (n=15) of the NLBP group and 33.33% (n=4) of the LBP group were found to participate in other types of sport. These sports included rugby, cricket, swimming, soccer, hockey, netball, table tennis, softball and athletics. The NLBP group spent a mean of two hours longer per week, playing other sports (NLBP: 3.48±2.89hrs; LBP: 1.42±2.39hrs) (see Figure 4.3).

The tennis questionnaire revealed that all but one participant in the LBP group played in singles as well as in doubles matches (p=0.364 between the two groups). In Figure 4.3, the NLBP group played singles for an average of two hours and doubles for one hour and twenty minutes per week. The LBP group played an average of two hours of singles and one hour and forty minutes of doubles per week. However, there was no difference between the period of time played in singles (p=0.813) or doubles (p=0.494) matches for the two groups.

Figure 4.3 indicates that the LBP group spent more hours practising tennis, playing tennis (singles and doubles) and doing other forms of exercise, although this was not significant. Eighty-six percent (86%) (n=18) of the NLBP group and 83.33% (n=10) of the LBP group reported that they did their own exercises and/or stretch regime.

The LBP group reported doing an average of two hours and forty minutes of other forms of exercise per week, while the NLBP group reported approximately two hours per week (see Figure 4.3). The other forms of exercise included stretches (warm-ups and cool downs), cardio (running, walking and cycling), strength training (home programmes, including sit-ups and push-ups), gym and Pilates.



	Practice	Singles	Doubles	Other Sports	Other Exercise
LBP Group	8,5	2	1,42	1,42	2,42
Std Dev	12	0,85	1	2,39	2,81
No-LBP Group	5	2,1	1,21	3,48	1,79
Std Dev	8	1,22	0,68	2,89	1,22

Figure 4. 3 Mean Hours per week participating in Sport and Exercise Activities for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; Std Dev – standard deviation; Practice – participate in tennis practise; Singles – participate in singles matches; Doubles – participate in doubles matches; Other Sports – participate in other sport types; Other Exercise – participate in other forms of exercise or stretches

Figure 4.4 displays the other exercise types engaged in by the two groups. This figure shows that the NLBP group did more strength training and the LBP group more stretches. However, there was no difference (p=0.854) between the two groups.

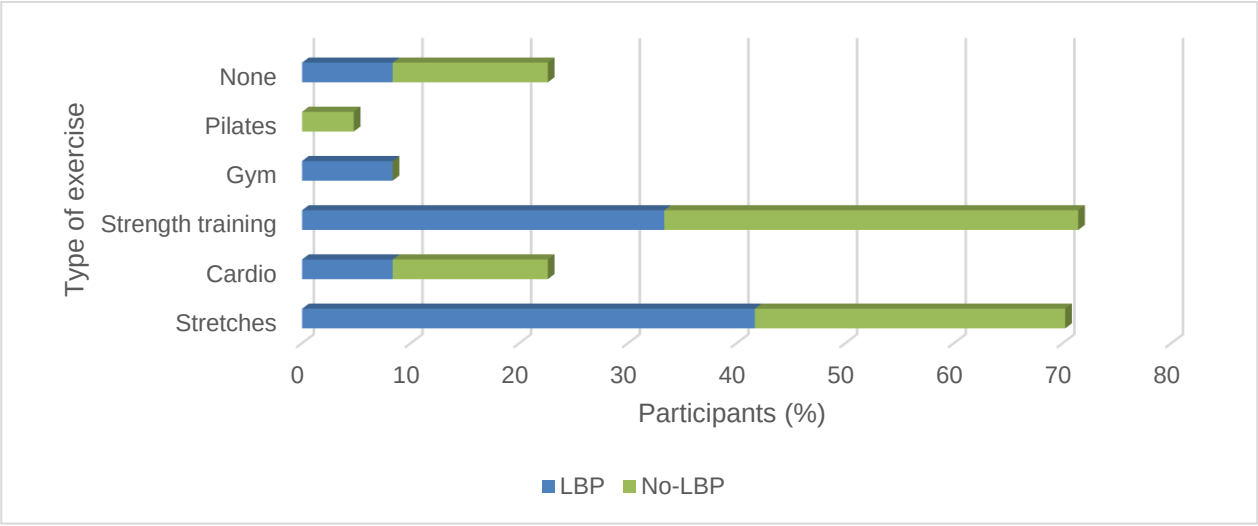


Figure 4. 4 Other Types of Exercises performed by the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain

The NLBP group made use of all types of hand grips during the serve, while the LBP group made more use of the semi-western hand grip (see Figure 4.5 – NLBP: Eastern=23.81%, Continental=28.57%, Western=23.81%, Semi-Western=23.81%) (LBP: Eastern=0%, Continental=16.67%, Western=16.67%, Semi-Western=66.67%). There was no difference in respect to hand placement between the two groups (p=0.083).

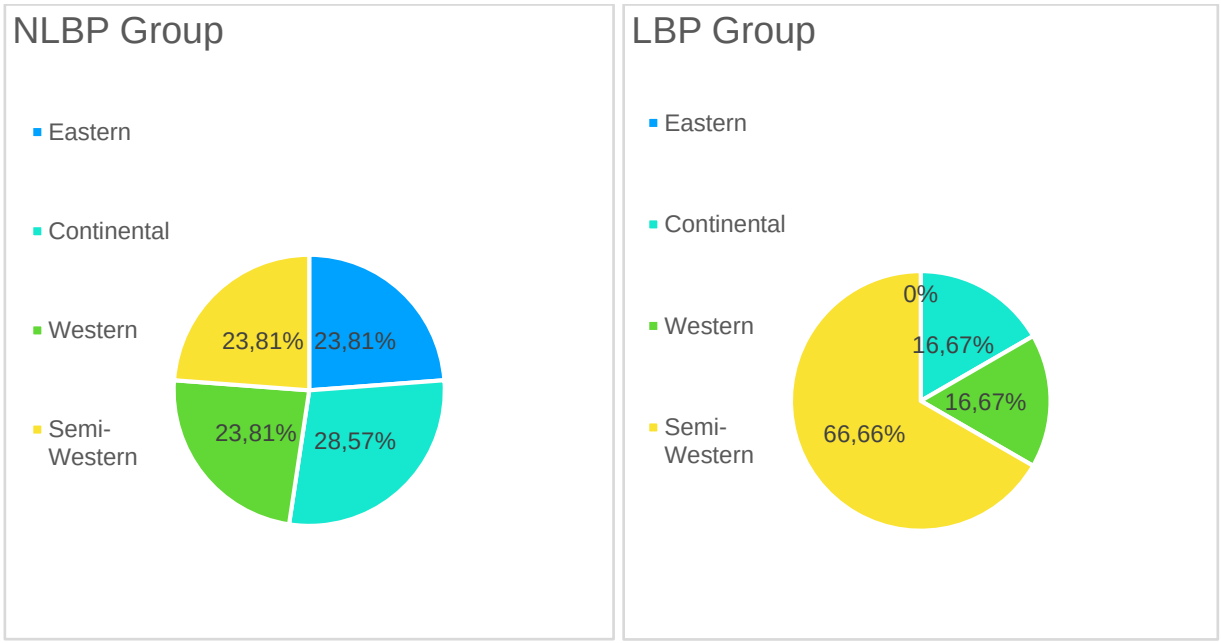


Figure 4. 5 Types of Hand Grips used during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain

4.3 Active Range of Motion Testing

As discussed in the data reduction section, the active ROM data should be interpreted as if the tennis player were right dominant. Table 4.3 shows that compared to the LBP group, the NLBP group exhibited greater active ROM in most of the tested directions. However, generally, the differences between the two groups were not significant.

For this study, the only difference found during the active ROM testing was for lumbar lateral flexion to the right. The NLBP group had a significantly higher median range of 36° for right-sided lateral flexion (p=0.012) compared to the LBP group (29°).

Table 4. 3 Active ROM of the NLBP and LBP Groups

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
Lumbar Flexion (°)	24	50	17.5	34	-1.124	96.000	0.261
Lumbar Extension (°)	45	60	45.5	50	-0.019	125.500	0.985
Lumbar Lateral Flexion to the Right (°)	36	25	29	15	-2.513	59.000	0.012
Lumbar Lateral Flexion to the Left (°)	34	26	30	18	-1.669	81.500	0.095
Lumbar Rotation to the Right (°)	67	59	61	37	-0.768	105.500	0.443
Lumbar Rotation to the Left (°)	65	59	67	50	-0.468	113.500	0.640
Hip Internal Rotation to the Right (°)	44	23	40.5	38	-1.447	87.500	0.148
Hip Internal Rotation to the Left (°)	44	25	39	32	-1.125	96.000	0.261
Hip External Rotation to the Right (°)	35	22	35	22	-0.056	124.500	0.955
Hip External Rotation to the Left (°)	35	19	37	25	-0.810	104.500	0.418

NLBP – participants without lower back pain; LBP – participants with lower back pain. Values display the maximum or end of the available active range of motion. The active range of motion data should be interpreted as if the tennis player were right dominant

4.4 Star Excursion Balance Test

No differences were found between the NLBP and LBP groups with regards to the leg length of the left and right legs (p=0.172 for both legs) (see Table 4.4). This indicates that there were no leg length discrepancies between the two groups; nor in the left and right limbs of the two groups.

Table 4. 4 Measurement of Leg Length for the NLBP and LBP groups

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
RIGHT LOWER LIMB (cm)	89.3	27.4	93.3	24.4	-1.366	89.500	0.172
LEFT LOWER LIMB (cm)	88.6	26.8	93.2	27.3	-1.366	89.500	0.172

NLBP – participants without lower back pain; LBP – participants with lower back pain

As explained in Chapter 3, the results from the SEBT were normalised to the participants' leg lengths. Furthermore, SEBT data should be interpreted as if the tennis players were right dominant. Table 4.5 displays the results of the normalised SEBT reach distances. When weight bearing is on the left leg and reaching is with the right leg, significant differences were found between the NLBP and LBP groups in the anteromedial reach (p=0.011), anterior reach (p=0.047) and posterolateral reach (p=0.047).

Furthermore, as indicated in Table 4.5, when weight bearing was on the right leg and reaching was with the left leg, there were significant differences in reach for the anterolateral reach (p=0.010), and posterior reach (p=0.041) between the two groups. In all the directions tested, the LBP group displayed a greater reach when compared to the NLBP group.

Table 4.5 Comparison between the Normalised SEBT Reach Distances in Participants with and without Lower Back Pain

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
RAM REACH (%)	80.45	26.34	84.51	30.42	-1.534	85.00	0.125
LAM REACH (%)	77.71	22.51	87.06	25.71	-2.545	58.00	**0.011**
RA REACH (%)	89.39	40.84	96.53	33.07	-1.834	77.00	0.067
LA REACH (%)	88.69	35.25	98.06	22.73	-1.983	73.00	**0.047**
RAL REACH (%)	89.84	26.97	101.29	32.91	-2.582	57.00	**0.010**
LAL REACH (%)	92.39	27.29	96.90	18.18	-1.647	82.00	0.100
RL REACH (%)	92.47	25.63	98.03	34.21	-1.834	77.00	0.067
LL REACH (%)	97.01	32.13	100.56	28.10	-1.647	82.00	0.100
RPL REACH (%)	98.32	29.11	104.43	35.26	-1.347	90.00	0.178
LPL REACH (%)	101.06	36.73	107.22	25.01	-1.984	73.00	**0.047**
RP REACH (%)	97.95	32.32	106.08	31.25	-2.040	71.50	**0.041**
LP REACH (%)	98.91	36.69	104.30	29.20	-1.796	78.00	0.072
RPM REACH (%)	90.50	44.60	98.89	47.69	-1.497	86.00	0.134
LPM REACH (%)	93.57	37.41	97.73	27.89	-0.898	102.00	0.369

NLBP – participants without lower back pain; LBP – participants with lower back pain; RAM – right anteromedial reach; LAM – left anteromedial reach; RA – right anterior reach; LA – left anterior reach; RAL – right anterolateral reach; LAL – left anterolateral reach; RL – right lateral reach; LL – left lateral reach; RPL – right posterolateral reach; LPL – left posterolateral reach; RP – right posterior reach; LP – left posterior reach; RPM – right posteromedial reach; LPM – left posteromedial reach. Values display the maximum or end of available reach. The SEBT data should be interpreted as if the participant were right dominant

4.5 Motion Analysis: Xsens MVN inertial motion capture system

Xsens MVN Studio software was used in order to analyse the various phases of the tennis serve. As discussed in the data processing section, markers were placed on the Xsens MVN

Studio software to identify specific phases in the tennis serve. The phases were used to look at points in the analytical data relating to kinetic motion, as well as to muscle activation. As discussed in the data reduction section, the results of the tennis serve should be interpreted as if the tennis players were right dominant. This means that the racquet would be in the right hand.

The results are explained in two categories, namely significant angles found and a description of the kinematics. For each phase, the motion-analysis data presented relate to the trunk, the right hip and the left hip.

No differences were found between the NLBP and LBP groups for the mean (NLBP: 3.50±2.17; LBP: 3.75±1.67; p=0.292) and greatest (NLBP: 5±2; LBP: 5±1; p=0.422) serve performance scores. This suggests that the participants' perspectives of execution during the tennis serve were well matched.

4.5.1 Preparation Phase: Start (PS)

Differences were found in the internal-external rotation angle (p=0.017) of the trunk, the internal-external rotation (p=0.003) of the right hip, the abduction-adduction angle (p=0.003) of the left hip, and the internal-external rotation (p=0.002) of the left hip, with the LBP group having a significant greater motion than the NLBP group. Significant differences were found in the flexion-extension angle (p=0.040) of the right hip and the flexion-extension angle (p=0.008) of the left hip, with the NLBP group having a significantly greater motion than the NLBP group (see Table 4.6 and Figure 4.6).

Table 4. 6 Kinematics of the Trunk and Hips at the Starting Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
TRUNK ABD/ADD PS (°)	-2.60	31.14	-4.59	26.55	-1.449	3974	0.147
TRUNK INT/EXT ROT PS (°)	16.03	46.60	21.52	62.20	-2.377	3614	0.017
TRUNK FLXN/EXT PS (°)	25.61	29.72	26.95	40.61	-1.093	4112	0.274
RIGHT HIP ABD/ADD PS (°)	-2.77	30.45	-2.88	21.47	-0.333	4407	0.739
RIGHT HIP INT/EXT ROT PS (°)	0.85	48.03	9.39	52.08	-2.949	3392	0.003
RIGHT HIP FLXN/EXT PS (°)	29.31	40.95	27.90	61.66	-2.050	3741	0.040
LEFT HIP ABD/ADD PS (°)	-2.62	23.16	-4.78	27.94	-3.016	3366	0.003
LEFT HIP INT/EXT ROT PS (°)	7.62	54.98	18.68	63.37	-3.078	3342	0.002
LEFT HIP FLXN/EXT PS (°)	18.73	42.27	15.50	28.04	-2.674	3499	0.008

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; PS – preparation phase: start of the serve. Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

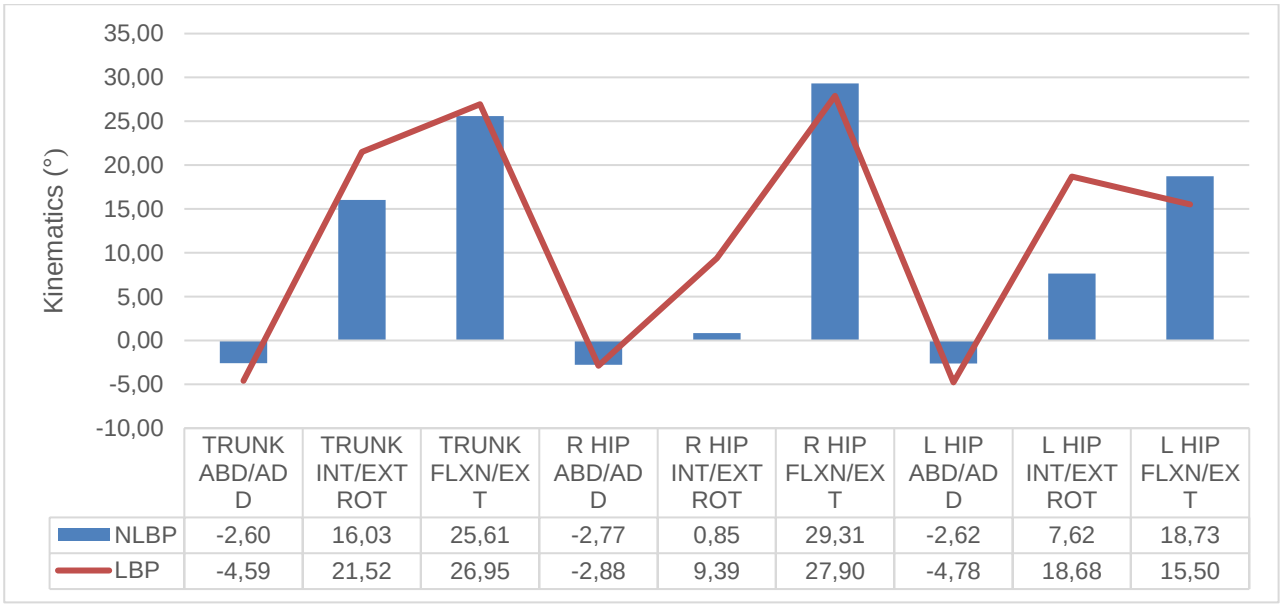


Figure 4. 6 Motion Analysis at the Starting Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; L – left; R – right; Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

Description of the motion at the Preparation Phase: Start (PS)

For both groups, the trunk at the PS phase was slightly flexed forward, with a small degree of lateral flexion and rotation to the left (Table 4.6). The bilateral hips were in a flexed position, adducted and internally rotated (Table 4.6). In both groups, the right hip was flexed more than the left. However, the left hip was more internally rotated than the right. A small degree of adduction was found in the right hip and the left hip of both groups.

4.5.2 Preparation Phase: Ball Release (PR)

During the ball-release point of the preparation phase, there was a difference found in the internal-external rotational angle ($p=0.006$) of the trunk, with the LBP group having a motion that was significantly greater than that in the NLBP group. A difference was found in the flexion-extension angle ($p=0.000$) of the right hip, the internal-external rotation ($p=0.007$) of the left hip, and the flexion-extension ($p=0.000$) of the left hip, with the motion in the NLBP group being significantly greater than that in the LBP group (see Table 4.7 and Figure 4.7).

Table 4. 7 Kinematics of the Trunk and Hips at the Ball Release Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
TRUNK ABD/ADD PR (°)	2.17	22.90	1.94	20.48	-0.480	4350	0.632
TRUNK INT/EXT ROT PR (°)	2.01	53.98	11.15	61.24	-2.741	3473	0.006
TRUNK FLXN/EXT PR (°)	10.83	44.31	9.85	40.12	-0.990	4152	0.322
RIGHT HIP ABD/ADD PR (°)	0.46	40.86	0.80	16.91	-0.792	4229	0.429
RIGHT HIP INT/EXT ROT PR (°)	6.31	54.67	13.21	63.11	-1.624	3906	0.104
RIGHT HIP FLXN/EXT PR (°)	32.02	70.77	21.51	44.94	-6.621	1968	0.000
LEFT HIP ABD/ADD PR (°)	-0.48	36.68	1.59	27.82	-0.392	4384	0.695
LEFT HIP INT/EXT ROT PR (°)	-7.50	50.81	-1.21	72.05	-2.702	3488	0.007
LEFT HIP FLXN/EXT PR (°)	31.12	78.99	25.68	59.23	-4.063	2960	0.000

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; PR – preparation phase: ball release. Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

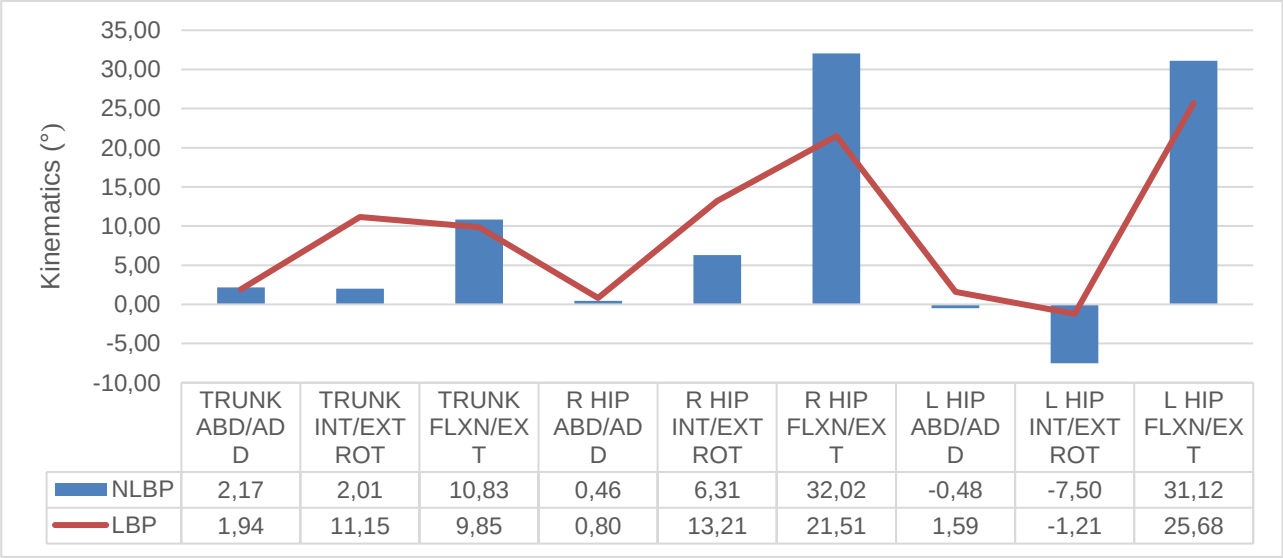


Figure 4. 7 Motion Analysis at the Ball Release Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; L – left; R – right; Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

Description of the motion at the Preparation Phase: Ball Release (PR)

From the start of the preparation phase to the point of ball release, the trunk was found to move marginally towards extension. The spine was still rotated towards the left, though in the NLBP group the rotation was closer to neutral than in the LBP group. In both groups, the spine moved through neutral and started to flex somewhat laterally towards the right, as can be seen in Table 4.7. The hips were flexing at the PR phase, though the NLBP group displayed more hip flexion than the LBP group in the right and left hips. The NLBP group displayed more hip flexion on the right side, while the LBP group displayed more hip flexion on the left side. The hip abduction ranges were close to neutral for the right and the left hips. The groups were internally rotated in the right hip and externally rotated in the left hip (see Table 4.7).

4.5.3 Preparation Phase: Loading (PL)

There were no significant differences in the trunk at the loading point of the preparation phase between the NLBP and LBP groups (see Table 4.8 and Figure 4.8). There was a difference in the abduction-adduction ($p=0.007$) for the right hip between the two groups, with the LBP group experiencing a greater degree of motion. A difference was found between the LBP and NLBP groups in the internal-external rotational angle ($p=0.000$) of the left hip, with the NLBP group experiencing a motion that was significantly greater than that of the LBP group.

Table 4. 8 Kinematics of the Trunk and Hips at the Loading Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
TRUNK ABD/ADD PL (°)	11.91	27.39	8.94	38.67	-0.980	4156	0.327
TRUNK INT/EXT ROT PL (°)	-5.78	67.81	1.63	62.27	-0.108	4494	0.914
TRUNK FLXN/EXT PL (°)	5.96	52.23	5.91	37.19	-0.449	4362	0.654
RIGHT HIP ABD/ADD PL (°)	11.94	70.84	13.36	55.74	-2.707	3486	0.007
RIGHT HIP INT/EXT ROT PL (°)	5.18	95.80	9.64	92.10	-0.330	4408	0.741
RIGHT HIP FLXN/EXT PL (°)	81.50	106.95	86.54	112.45	-1.637	3901	0.102
LEFT HIP ABD/ADD PL (°)	-10.95	59.99	-10.33	52.71	-1.374	4003	0.169
LEFT HIP INT/EXT ROT PL (°)	-11.57	53.92	-3.45	56.43	-3.707	3098	0.000
LEFT HIP FLXN/EXT PL (°)	84.15	73.83	75.88	107.01	-0.655	4282	0.513

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; PL – preparation phase: loading point. Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

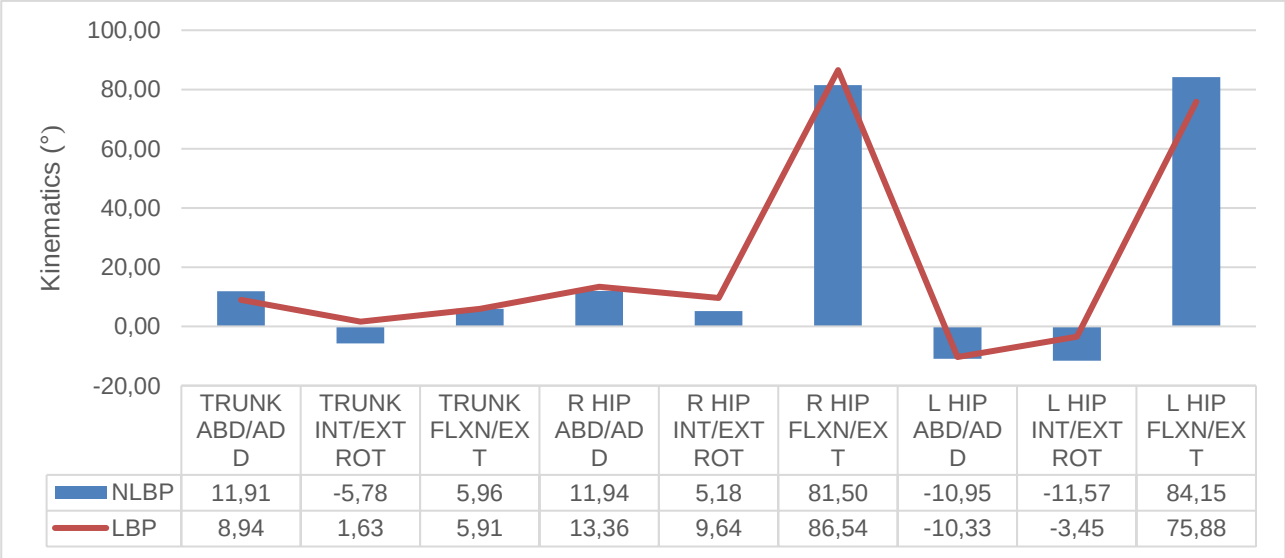


Figure 4. 8 Motion Analysis at the Loading Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; L – left; R – right; Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

Description of the motion at the Preparation Phase: Loading (PL)

The trunk was continuing in lateral flexion and rotation motions to the right, toward the racquet arm. Interestingly, the NLBP group was already in rotation to the right, though the LBP group was still in rotation to the left. As can be seen in Table 4.8, while the trunk was slowly loading into the coil position, it remained in a marginally flexed position during the PL phase. Compared to the other phases, the PL phase for both groups showed maximum hip flexion in the bilateral hips. The right hip was internally rotated and abducted, with the LBP group showing a greater degree of motion. The left hip was externally rotated and adducted, with the NLBP group displaying more external rotation in the left hip compared to the LBP group (Table 4.8).

4.5.4 Preparation Phase: Cocking (PC)

Differences were found in the internal-external rotational angle ($p=0.017$) of the right hip, the flexion-extension ($p=0.021$) of the right hip, and the internal-external rotation ($p=0.047$) of the left hip, with the NLBP group experiencing greater motion than the LBP group (Table 4.9 and Figure 4.9). No differences were found between the two groups in terms of the trunk motions during the cocking phase.

Table 4. 9 Kinematics of the Trunk and Hips at the Cocking Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
TRUNK ABD/ADD PC (°)	-4.76	56.56	-9.33	34.19	-1.598	3916	0.110
TRUNK INT/EXT ROT PC (°)	-9.74	56.90	1.37	66.60	-1.477	3963	0.140
TRUNK FLXN/EXT PC (°)	-17.82	47.91	-16.17	72.31	-0.518	4335	0.604
RIGHT HIP ABD/ADD PC (°)	-5.90	43.74	-5.84	37.96	-0.954	4166	0.340
RIGHT HIP INT/EXT ROT PC (°)	-6.64	60.79	2.19	68.36	-2.382	3612	0.017
RIGHT HIP FLXN/EXT PC (°)	9.06	79.40	-0.15	86.24	-2.310	3640	0.021
LEFT HIP ABD/ADD PC (°)	-5.64	43.69	-5.66	37.56	-1.116	4103	0.264
LEFT HIP INT/EXT ROT PC (°)	-3.74	59.74	5.35	79.89	-1.990	3764	0.047
LEFT HIP FLXN/EXT PC (°)	9.94	91.49	6.91	75.89	-1.047	4130	0.295

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; PC – preparation phase: cocking point. Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

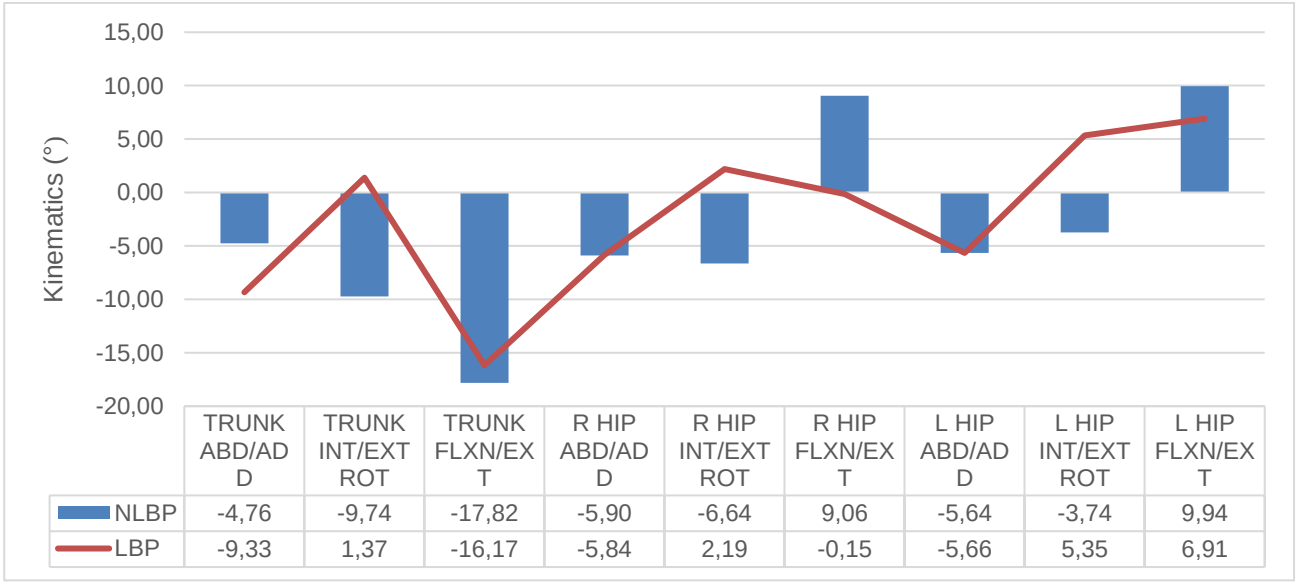


Figure 4. 9 Motion Analysis at the Cocking Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; L – left; R – right; Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

Description of the motion at the Preparation Phase: Cocking (PC)

During the PC phase, the trunk was extended whilst starting to flex laterally to the left (see Table 4.9). The NLBP group made use of more trunk extension, whilst the LBP group made use of more lateral flexion at this point. Furthermore, the NLBP group was rotated to the right, whilst the LBP group was still rotated to the left. In both groups, the bilateral hips were extending. However, the right hip of the LBP group was already in extension ROM. The hips were adducting. At the PC phase, the bilateral hips in the case of the NLBP group were externally rotated, whilst those of the LBP group were internally rotated (see Table 4.9).

4.5.5 Acceleration Phase: Ball Contact (AC1)

There were significant differences in motion between the flexion-extension ($p=0.005$) of the right hip and the flexion-extension ($p=0.045$) of the left hip, with the NLBP group having a greater angle than the LBP group (see Table 4.10 and Figure 4.10). A significant difference was observed in the internal-external rotational angle ($p=0.010$) of the left hip, with the LBP group experiencing greater motion than the NLBP group. No differences were observed between the two groups in respect to the trunk motions.

Table 4. 10 Kinematics of the Trunk and Hips at the Ball Contact Point of the Acceleration Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
TRUNK ABD/ADD AC1 (°)	-21.57	39.55	-20.11	35.34	-1.635	3902	0.102
TRUNK INT/EXT ROT AC1 (°)	-0.42	57.19	7.34	51.44	-0.606	4301	0.545
TRUNK FLXN/EXT AC1 (°)	17.30	59.37	16.26	41.77	-1.134	4096	0.257
RIGHT HIP ABD/ADD AC1 (°)	-14.43	51.17	-12.87	46.50	-0.993	4151	0.321
RIGHT HIP INT/EXT ROT AC1 (°)	-4.87	77.42	4.08	64.78	-1.067	4122	0.286
RIGHT HIP FLXN/EXT AC1 (°)	19.23	90.39	14.37	110.67	-2.810	3446	0.005
LEFT HIP ABD/ADD AC1 (°)	-9.16	44.59	-9.55	55.60	-0.727	4254	0.467
LEFT HIP INT/EXT ROT AC1 (°)	1.41	55.30	10.59	60.59	-2.583	3534	0.010
LEFT HIP FLXN/EXT AC1 (°)	27.55	65.51	22.83	92.52	-2.006	3758	0.045

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; AC1 – acceleration phase: ball contact. Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

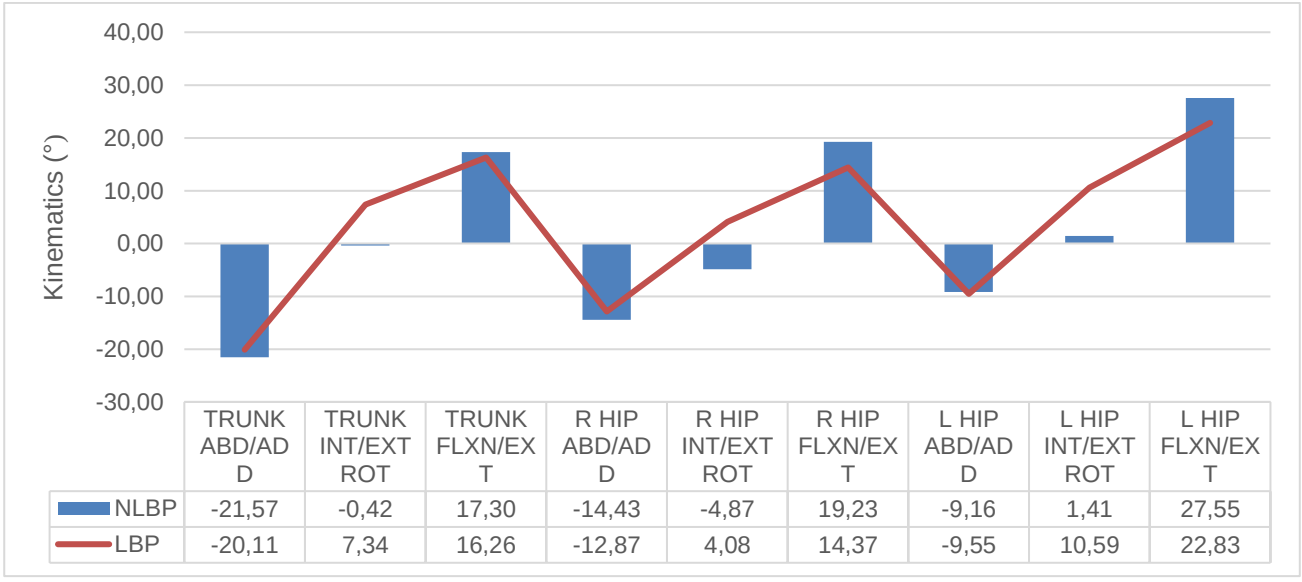


Figure 4. 10 Motion Analysis at the Ball Contact Point of the Acceleration Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; L – left; R – right; Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

Description of the motion at the Acceleration Phase: Ball Contact (AC1)

At ball-contact point, the spine was forward flexing whilst laterally flexing to the left and rotating from the right to the left (see Table 4.10). In the NLBP group, the trunk was still in rotation to the right but close to neutral. In the LBP group, the trunk was rotating to the left (more rotation than in the PC phase). Both groups were laterally flexing to the left. Data in Table 4.10 indicate that the NLBP group made use of more hip flexion than the LBP group. The left hip indicated a greater degree of flexion compared to the right hip. The hips were adducted in both groups, although the right hip was adducted more than the left. The right hip of the NLBP group was externally rotated, whilst the right hip of the LBP group was internally rotated. Both groups displayed internal rotation of the left hip.

4.5.6 Acceleration Phase: Maximum Shoulder Abduction (AC2)

In this study, the moment of ball contact rarely occurred at the exact time that the maximum abduction of the shoulder (NLBP group=0.84% and LBP group=2.78%) was being experienced. In the majority of participants, the point of maximum shoulder abduction occurred after ball contact (NLBP group before=20.17%, after=78.99% and LBP group before=11.11%, after=86.11%).

There were significant differences in motion between the flexion-extension (p=0.009) of the right hip, and the flexion-extension (p=0.009) of the left hip, with the NLBP group presenting with a greater angle than the LBP group (see Table 4.11 and Figure 4.11). A difference was observed in the internal-external rotational angle (p=0.018) of the left hip, with the LBP group experiencing greater motion than the NLBP group. No significant differences were observed between the groups in terms of the trunk motions.

Table 4. 11 Kinematics of the Trunk and Hips at the Maximum Shoulder Abduction Point of the Acceleration Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
TRUNK ABD/ADD AC2 (°)	-17.61	40.96	-18.03	33.25	-0.902	4186	0.367
TRUNK INT/EXT ROT AC2 (°)	2.87	57.18	6.54	51.41	-0.229	4447	0.819
TRUNK FLXN/EXT AC2 (°)	21.01	67.19	22.75	48.38	-1.083	4116	0.279
RIGHT HIP ABD/ADD AC2 (°)	-12.63	51.90	-11.63	43.38	-0.835	4212	0.404
RIGHT HIP INT/EXT ROT AC2 (°)	-3.32	79.92	5.09	77.32	-1.297	4033	0.195
RIGHT HIP FLXN/EXT AC2 (°)	24.01	117.27	18.97	127.59	-2.612	3523	0.009
LEFT HIP ABD/ADD AC2 (°)	-5.74	47.80	-7.44	57.48	-0.008	4533	0.994
LEFT HIP INT/EXT ROT AC2 (°)	3.49	50.55	8.66	68.77	-2.367	3618	0.018
LEFT HIP FLXN/EXT AC2 (°)	32.89	59.83	25.05	95.24	-2.614	3522	0.009

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; AC2 – acceleration phase: maximum shoulder abduction. Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

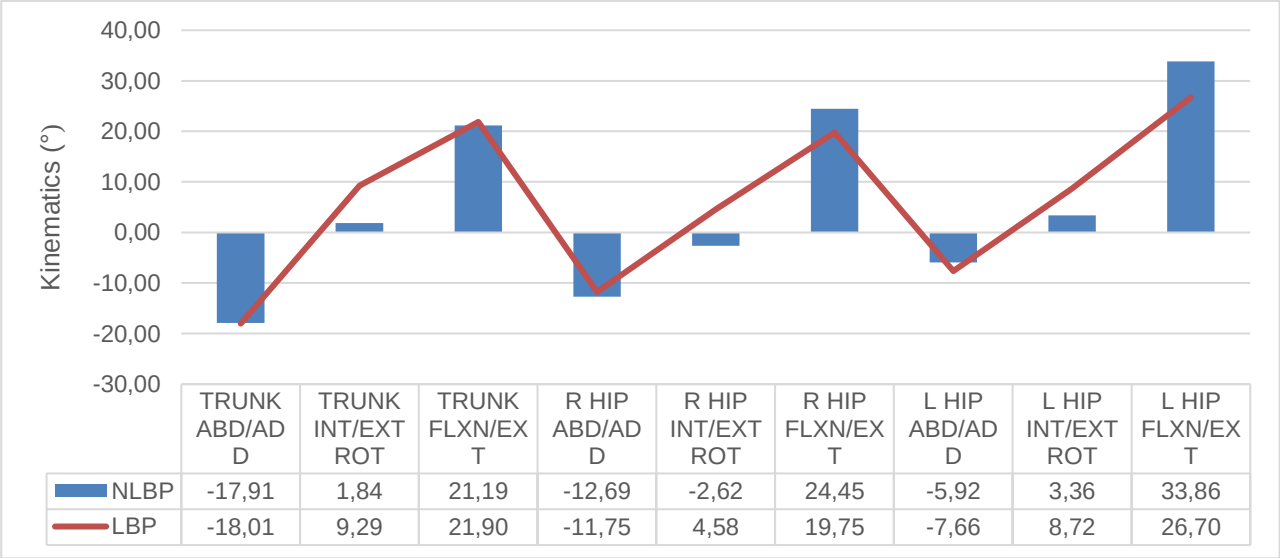


Figure 4. 11 Motion Analysis at the Maximum Shoulder Abduction Point of the Acceleration Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; L – left; R – right; Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

Description of the motion at the Acceleration Phase: Maximum Shoulder Abduction (AC2)

Table 4.11 displays the trunk motion during the AC2 phase. The trunk was in a flexed position, rotating and laterally flexing toward the left (away from the racquet arm). The bilateral hips were in flexion, with the left hip flexed more than the right. Both hips were adducted, with the right leg more than the left. As in the AC1 phase, the right hip was externally rotated in the NLBP group and internally rotated in the LBP group, though this was not significant. The left hip was internally rotated in both groups. The tennis player was still air-borne at this point and presumably, the biomechanical chain was preparing for the landing of the player and the finishing moment of the tennis serve (Table 4.11).

4.5.7 Deceleration Phase: Final (DF)

Differences were found in the trunk between the LBP and the NLBP groups in the abduction-adduction ($p=0.009$) and the internal-external rotation ($p=0.046$) angles, with the LBP group experiencing greater motion than the NLBP group. A significant difference in motion was also found in the flexion-extension ($p=0.002$) of the trunk, with the NLBP group displaying a greater angle (see Table 4.12).

There was a difference in motion between the flexion-extension angles ($p=0.002$) of the right hip, with the LBP group having a higher average than the LBP group. Differences were observed in the abduction-adduction angle ($p=0.056$) of the left hip, its internal-external rotation ($p=0.004$) and its flexion-extension ($p=0.012$), with the LBP group experiencing a greater degree of motion (see Table 4.12 and Figure 4.12).

Table 4. 12 Kinematics of the Trunk and Hips at the Final Point of the Deceleration Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
TRUNK ABD/ADD DF (°)	-2.89	54.02	-7.17	41.51	-2.596	3529	0.009
TRUNK INT/EXT ROT DF (°)	22.24	55.90	27.37	68.03	-1.993	3763	0.046
TRUNK FLXN/EXT DF (°)	35.54	61.54	29.69	46.80	-3.029	3361	0.002
RIGHT HIP ABD/ADD DF (°)	-3.93	54.05	-1.30	38.99	-0.678	4273	0.498
RIGHT HIP INT/EXT ROT DF (°)	5.40	70.92	7.96	93.90	-0.931	4175	0.352
RIGHT HIP FLXN/EXT DF (°)	78.32	142.08	89.54	147.15	-3.050	3353	0.002
LEFT HIP ABD/ADD DF (°)	-0.15	55.82	-1.17	46.86	-1.913	3794	0.056
LEFT HIP INT/EXT ROT DF (°)	14.54	70.52	23.81	57.19	-2.918	3404	0.004
LEFT HIP FLXN/EXT DF (°)	49.91	84.53	56.73	67.17	-2.519	3559	0.012

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; DF – deceleration phase: finish of serve. Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

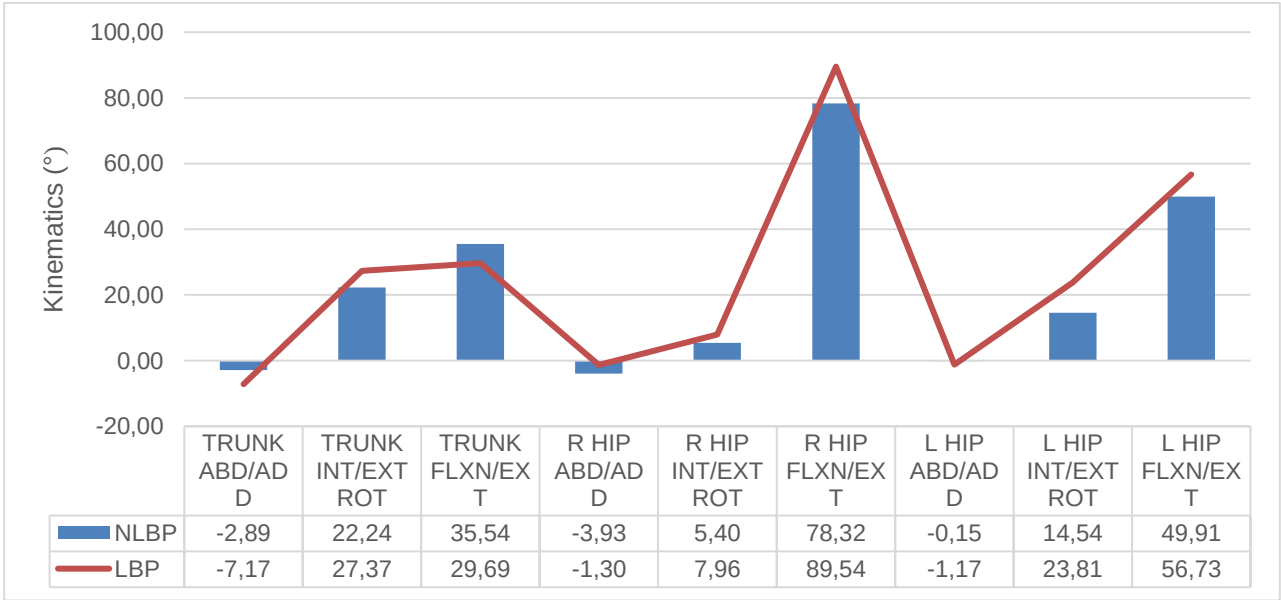


Figure 4. 12 Motion Analysis at the Finish Point of the Deceleration Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; L – left; R – right; Values display the degree of motion at that point during the tennis serve. The kinematic data should be interpreted as if the tennis player were right dominant. [B]Z-axis (sagittal plane) – flexion (+ve) and extension (-ve); [B]X-axis (frontal plane) – abduction (+ve) and adduction (-ve); [B]Y-axis (transverse plane) – internal rotation (+ve) and external rotation (-ve)

Description of the motion at the Deceleration Phase: Final (DF)

The data presented in Table 4.12 shows that the trunk was forward flexed, laterally flexed and rotated to the left during the DF phase. The bilateral hips were flexed, adducted and internally rotated during the DF phase (see Table 4.12). In both groups, the right hip was flexed more than the left hip, and the left hip was internally rotated more than the right hip. For the NLBP group, the right hip was more adducted compared to the left. The LBP group displayed almost the same degree of adduction in both hips.

4.6 Muscle Activation Analysis: EMG at each Phase of the Tennis Serve

The same markers (phases) used in the motion analysis were used to analyse the EMG data. The data were differentiated into two categories for the sake of an explanation, namely significant activation found and a description of the muscle activation at that point. [The muscle-activation data for the anterior trunk muscles and the posterior trunk muscles, for each phase, are displayed in one table.]

4.6.1 Preparation Phase: Start (PS)

Differences were found in the muscle activity of the left ES (p=0.088), the right ES (p=0.000) and the right GM (p=0.083) muscles for the two groups (see Table 4.13 and Figure 4.13). The NLBP group showed a higher average intensity than the LBP group. No differences were found between the two groups in respect to the RA and EO muscle activation, however.

Table 4. 13 Anterior and Posterior Trunk Muscle Activation at the Start Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
EMG LEFT RA PS (%)	0.93	15.24	1.00	3.61	-0.621	4295	0.534
EMG RIGHT RA PS (%)	0.78	30.72	0.84	2.39	-0.322	4411	0.747
EMG LEFT EO PS (%)	1.93	16.83	2.51	5.71	-1.575	3925	0.115
EMG RIGHT EO PS (%)	1.44	41.43	1.56	5.64	-0.861	4202	0.389
EMG LEFT ES PS (%)	6.28	26.42	4.35	33.85	-1.704	3875	0.088
EMG RIGHT ES PS (%)	19.18	50.70	13.78	51.10	-3.576	3149	0.000
EMG LEFT GM PS (%)	5.12	25.88	3.95	18.49	-0.879	4195	0.379
EMG RIGHT GM PS (%)	5.27	102.59	3.95	21.20	-1.735	3863	0.083

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; PS – preparation phase: start point. Values display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

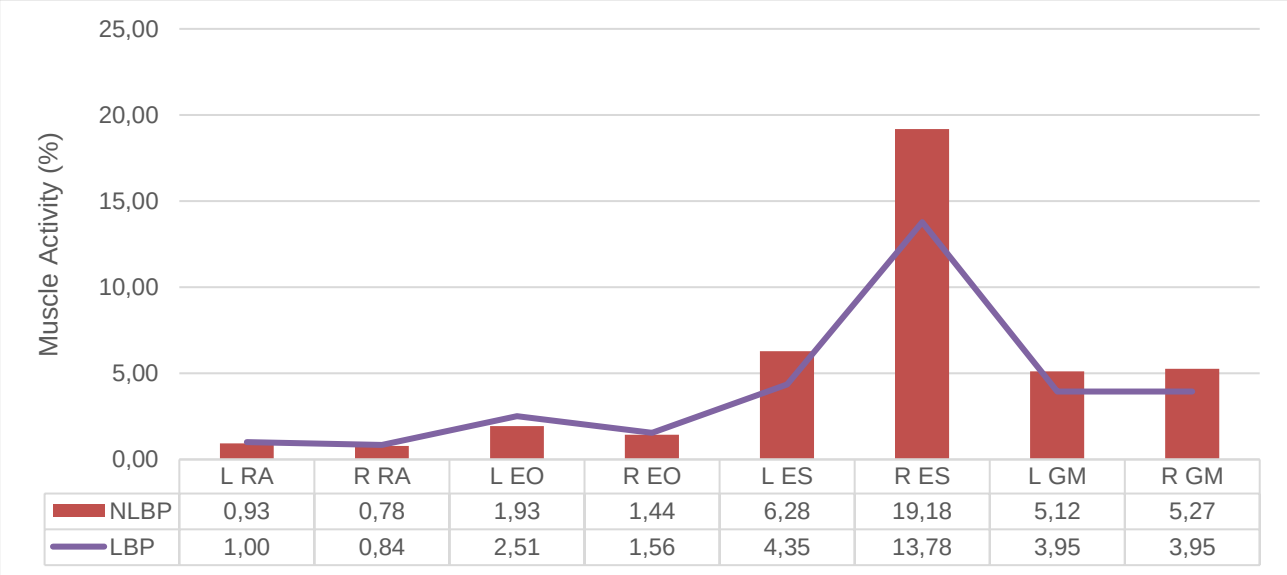


Figure 4. 13 Muscle Activation at the Starting Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; L – left; R – right; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; Values in the figure display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Description of the muscle activation at the Preparation Phase: Start (PS)

The bilateral RA and EO, were all activated to a small degree (Table 4.13). In both groups, the right ES muscle showed a larger level of muscle activation than the left side. Furthermore, as opposed to the LBP group, the NLBP group showed a significantly larger level of muscle activation of the right ES. There was close-to-equal activation in the right compared to the left GM, of each group (see Table 4.13).

4.6.2 Preparation Phase: Ball Release (PR)

A difference was found in the muscle activation of the right EO muscle (p=0.001), with the NLBP group having a higher intensity than the LBP group (see Table 4.14 and Figure 4.14). No significant differences were found in the RA, ES and GM muscle activity during the PR phase.

Table 4. 14 Anterior and Posterior Trunk Muscle Activation at the Ball Release Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
EMG LEFT RA PR (%)	2.33	20.48	1.84	13.43	-0.812	4221	0.417
EMG RIGHT RA PR (%)	1.34	16.98	1.57	13.39	-0.010	4532	0.992
EMG LEFT EO PR (%)	5.50	32.91	4.40	22.80	-0.848	4207	0.396
EMG RIGHT EO PR (%)	5.01	21.42	2.63	26.36	-3.395	3219	0.001
EMG LEFT ES PR (%)	5.37	62.45	4.08	27.03	-1.446	3975	0.148
EMG RIGHT ES PR (%)	7.80	75.41	6.75	50.55	-0.699	4265	0.485
EMG LEFT GM PR (%)	2.37	22.33	3.34	74.01	-1.343	4015	0.179
EMG RIGHT GM PR (%)	4.66	61.30	5.48	29.81	-0.278	4428	0.781

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; PR – preparation phase: ball release point. Values display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant



	L RA	R RA	L EO	R EO	L ES	R ES	L GM	R GM
NLBP	2,33	1,34	5,50	5,01	5,37	7,80	2,37	4,66
LBP	1,84	1,57	4,40	2,63	4,08	6,75	3,34	5,48

Figure 4. 14 Muscle Activation at the Ball Release Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; L – left; R – right; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; Values in the figure display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Description of the muscle activation at the Preparation Phase: Ball Release (PR)

In both groups, the left RA had a marginally larger level of muscle activation compared to the right (see Table 4.14). In the NLBP group, the left and right EO displayed a close to equal level of muscle activation. However, in the LBP group, the right EO showed a lower level of muscle activation compared to the left. Conversely for both groups, the right ES, as well as the right GM, displayed increased activation as opposed to the activation levels of these muscles on the left side (Table 4.14).

4.6.3 Preparation Phase: Loading (PL)

There were significant differences in muscle activation between the left RA (p=0.054) and the right EO (p=0.055), with the NLBP group having a higher activity level than the LBP group (see Table 4.15 and Figure 4.15). A significant difference was also found between the muscle activity of the right ES (p=0.003). In this case, the LBP group had a higher average

for this variable than the NLBP group. No differences were found between the two groups in terms of the GM muscle activity for the loading phase.

Table 4. 15 Anterior and Posterior Trunk Muscle Activation at the Loading Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
EMG LEFT RA PL (%)	7.91	64.03	4.92	33.92	-1.926	3789	0.054
EMG RIGHT RA PL (%)	2.98	18.59	3.20	25.80	-0.415	4375	0.678
EMG LEFT EO PL (%)	12.47	107.64	18.20	80.15	-0.719	4257	0.472
EMG RIGHT EO PL (%)	9.55	68.71	6.32	107.95	-1.921	3791	0.055
EMG LEFT ES PL (%)	5.90	84.12	4.93	60.28	-1.160	4086	0.246
EMG RIGHT ES PL (%)	4.07	23.96	5.39	61.20	-3.001	3372	0.003
EMG LEFT GM PL (%)	5.38	125.08	6.46	63.25	-0.843	4209	0.399
EMG RIGHT GM PL (%)	6.23	111.28	5.52	73.84	-0.804	4224	0.421

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; PL – preparation phase: loading point. Values display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

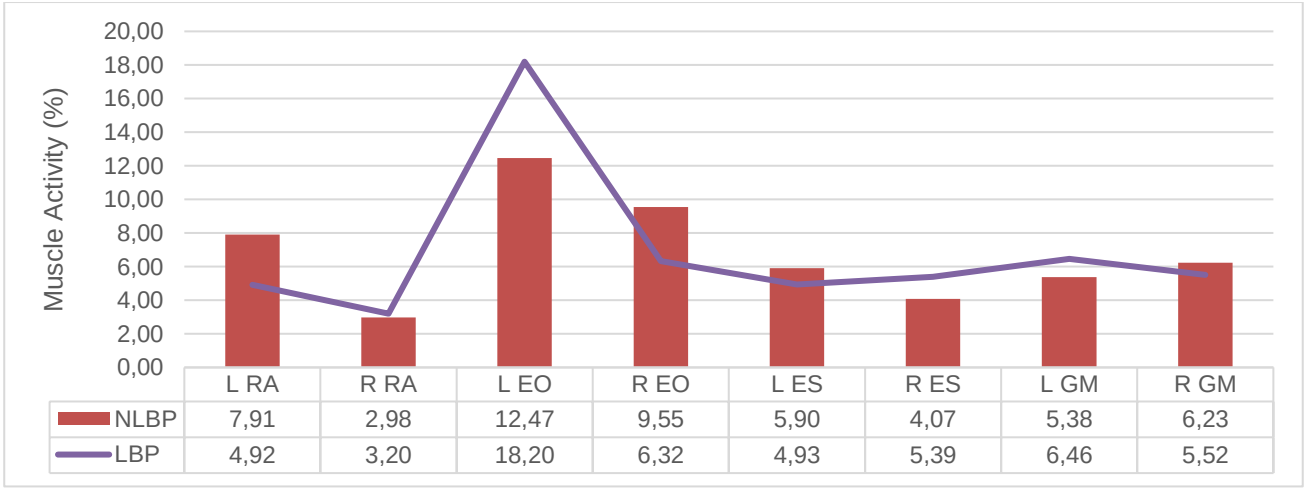


Figure 4. 15 Muscle Activation at the Loading Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; L – left; R – right; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; Values in the figure display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Description of the muscle activation at the Preparation Phase: Loading (PL)

The muscle activity of the left RA and the left EO was considerable in both groups. The muscle activation for the left RA muscle, was larger in the NLBP group, whilst, the activity in the left EO muscle was larger in the LBP group (see Table 4.15). The LBP group presented with higher levels of muscle activation in the right ES muscles, whilst the NLBP group displayed higher levels of muscle activation in the left ES muscles. In the GM muscles, the right GM was more active in the NLBP group while the left GM was more active in the LBP group (Table 4.15).

4.6.4 Preparation Phase: Cocking (PC)

A difference was found in the left RA ($p=0.013$) muscle activity. In this respect, the NLBP group had a higher average level of activation than the LBP group (see Table 4.16 and Figure 4.16). Furthermore, a significant difference was found in the muscle activity of the right RA ($p=0.078$), with higher activation levels in the LBP group than in the NLBP group. No significant differences were found in the two groups in respect to the muscle activity of the EO, ES and GM in the cocking phase.

Table 4. 16 Anterior and Posterior Trunk Muscle Activation at the Cocking Point of the Preparation Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
EMG LEFT RA PC (%)	32.37	151.18	20.11	87.78	-2.480	3574	0.013
EMG RIGHT RA PC (%)	4.58	69.51	5.94	95.34	-1.763	3852	0.078
EMG LEFT EO PC (%)	46.77	168.72	42.57	201.07	-0.054	4515	0.957
EMG RIGHT EO PC (%)	14.80	108.38	12.32	71.12	-0.366	4394	0.714
EMG LEFT ES PC (%)	21.28	171.95	20.30	92.27	-0.737	4250	0.461
EMG RIGHT ES PC (%)	7.18	78.35	8.06	70.09	-1.029	4137	0.304
EMG LEFT GM PC (%)	20.55	140.46	19.10	145.76	-0.575	4313	0.565
EMG RIGHT GM PC (%)	12.12	159.36	11.26	100.18	-0.596	4305	0.551

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; PC – preparation phase: cocking point. Values display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

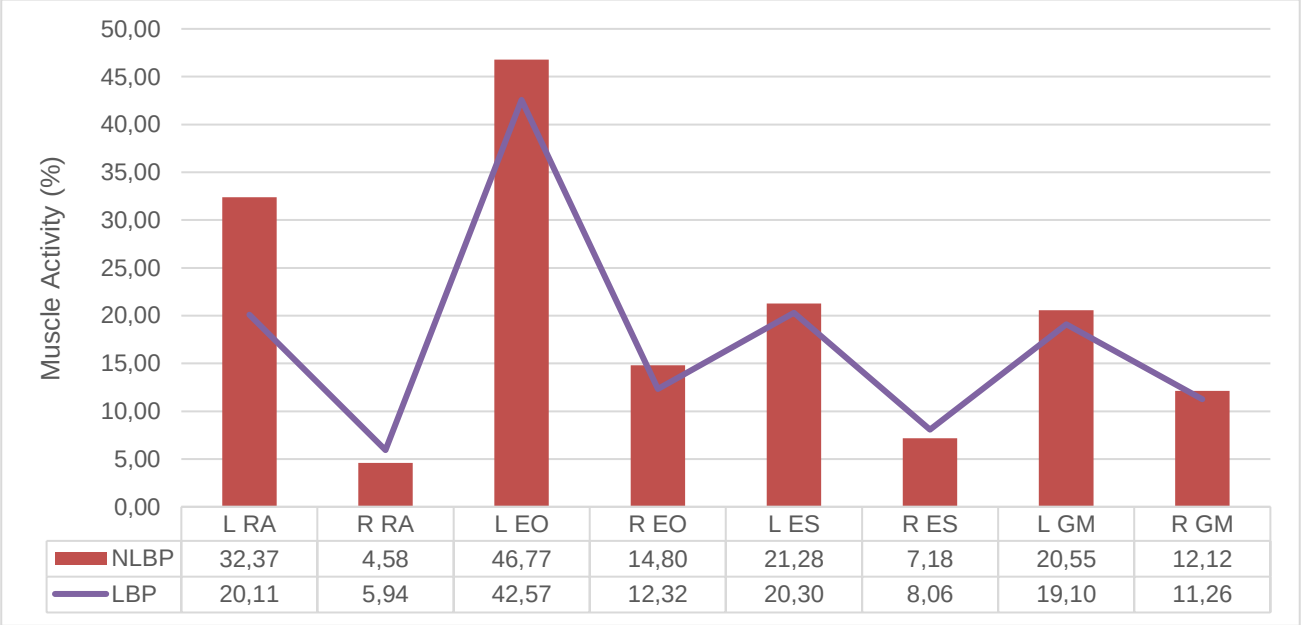


Figure 4. 16 Muscle Activation at the Cocking Point of the Preparation Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; L – left; R – right; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; Values in the figure display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Description of the muscle activation at the Preparation Phase: Cocking (PC)

In the cocking phase, the left anterior and left posterior trunk muscles had a higher level of muscle activation compared to the right side, in both groups (see Table 4.16).

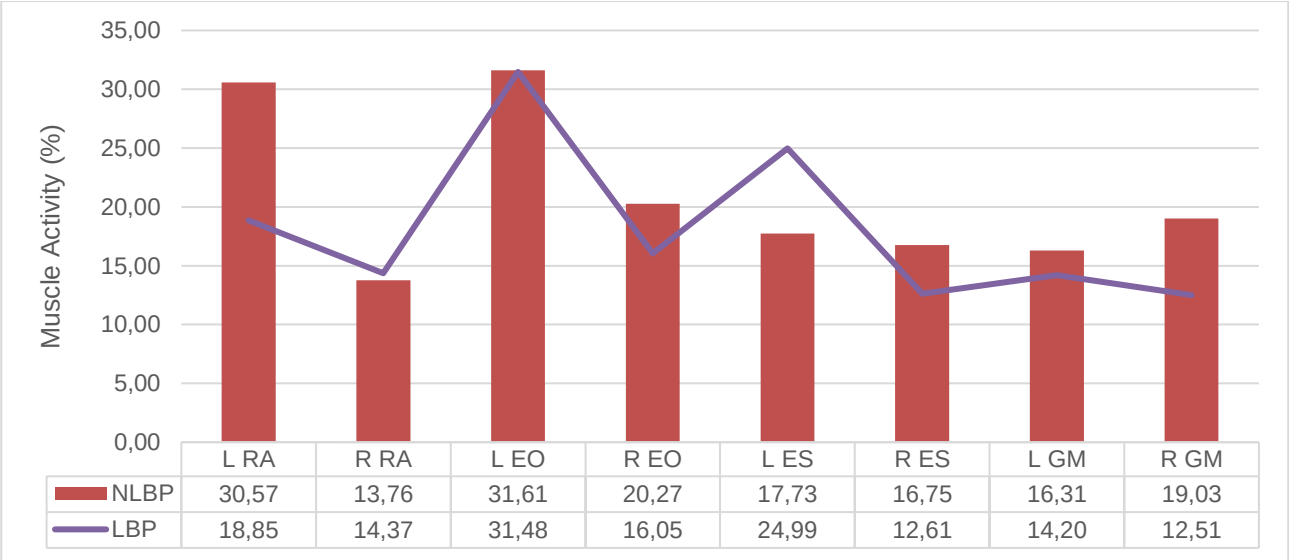
4.6.5 Acceleration Phase: Ball Contact (AC1)

There was a difference in the muscle activation of the right EO (p=0.051), with the NLBP group having a higher average than the LBP group (see Table 4.17 and Figure 4.17). A significant difference was also found between the muscle activity of the left ES (p=0.015), where the LBP group had a higher average than the NLBP group. There were no differences in the muscle activation levels of the RA and GM muscles between the NLBP and LBP groups at the ball-contact point of the acceleration phase.

Table 4. 17 Anterior and Posterior Trunk Muscle Activation at the Ball Contact Point of the Acceleration Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
EMG LEFT RA AC1 (%)	30.57	136.39	18.85	118.15	-1.617	3909	0.106
EMG RIGHT RA AC1 (%)	13.76	71.11	14.37	97.50	-0.134	4484	0.893
EMG LEFT EO AC1 (%)	31.61	139.45	31.48	195.89	-0.601	4303	0.548
EMG RIGHT EO AC1 (%)	20.27	131.31	16.05	58.04	-1.952	3779	0.051
EMG LEFT ES AC1 (%)	17.73	392.88	24.99	112.44	-2.439	3590	0.015
EMG RIGHT ES AC1 (%)	16.75	93.79	12.61	122.57	-0.387	4386	0.699
EMG LEFT GM AC1 (%)	16.31	86.16	14.20	129.50	-0.199	4459	0.843
EMG RIGHT GM AC1 (%)	19.03	139.29	12.51	108.11	-1.168	4083	0.243

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; AC1 – acceleration phase: ball contact point. Values display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant



	L RA	R RA	L EO	R EO	L ES	R ES	L GM	R GM
NLBP	30,57	13,76	31,61	20,27	17,73	16,75	16,31	19,03
LBP	18,85	14,37	31,48	16,05	24,99	12,61	14,20	12,51

Figure 4. 17 Muscle Activation at the Ball Contact Point of the Acceleration Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; L – left; R – right; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; Values in the figure display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Description of the muscle activation at the Acceleration Phase: Ball Contact (AC1)

Both groups indicated higher levels of muscle activation in the left RA and the left EO, compared to the right side (Table 4.17). Interestingly, the NLBP group had a close-to-equal level of muscle activation in the left and the right ES muscles, whilst the LBP group had higher activation levels in the left ES muscles. The NLBP group displayed a higher level of muscle activation in the right GM, whilst the LBP group had a higher level of activation in the left GM when compared to their associated other side (see Table 4.17).

4.6.6 Acceleration Phase: Maximum Shoulder Abduction (AC2)

A statistically significant difference was found between the left RA (p=0.077) and the right EO (p=0.021) muscle activity, with a higher average for the NLBP group (see Table 4.18 and Figure 4.18). There were significant differences found in the muscle activation of the left

ES (p=0.000), with the LBP group having a higher average than the NLBP group. No significant differences were found in muscle activity in the GM during the acceleration phase.

Table 4. 18 Anterior and Posterior Trunk Muscle Activation at the Maximum Shoulder Abduction Point of the Acceleration Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
EMG LEFT RA AC2 (%)	22.33	136.12	14.67	99.36	-1.769	3850	0.077
EMG RIGHT RA AC2 (%)	10.96	71.25	5.11	90.65	-1.243	4054	0.214
EMG LEFT EO AC2 (%)	23.74	136.02	26.23	106.91	-0.227	4448	0.821
EMG RIGHT EO AC2 (%)	16.81	131.51	13.05	57.82	-2.302	3643	0.021
EMG LEFT ES AC2 (%)	17.76	385.28	33.33	110.82	-4.416	2823	0.000
EMG RIGHT ES AC2 (%)	23.00	112.33	23.07	122.80	-0.449	4362	0.654
EMG LEFT GM AC2 (%)	16.22	97.82	18.54	148.83	-0.596	4305	0.551
EMG RIGHT GM AC2 (%)	19.85	168.68	16.11	107.37	-0.240	4443	0.811

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; AC2 – acceleration phase: maximum shoulder abduction point. Values display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant



Figure 4. 18 Muscle Activation at the Maximum Shoulder Abduction Point of the Acceleration Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; L – left; R – right; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; Values in the figure display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Description of the muscle activation at the Acceleration Phase: Maximum Shoulder Abduction (AC2)

The left RA and left EO had a higher activity level compared to their counterparts (Table 4.18). In the NLBP group, the right ES and the right GM, had higher levels of muscle activation, whilst in the LBP group the levels of muscle activity in the left ES and the left GM were higher (Table 4.18).

4.6.7 Deceleration Phase: Final (DF)

Significant differences in muscle activity were found in the left RA (p=0.036), right RA (p=0.069), left EO (p=0.000), left ES (p=0.001), and the right ES (p=0.021), with the LBP group having a higher average than the NLBP group (see Table 4.19 and Figure 4.19). The two groups showed no significant differences in muscle activity in the GM in the deceleration phase.

Table 4. 19 Anterior and Posterior Trunk Muscle Activation at the Final Point of the Deceleration Phase

	Group				z	u	p
	NLBP (n=21)		LBP (n=12)				
	Median	Range	Median	Range			
EMG LEFT RA DF (%)	1.76	53.58	2.84	31.43	-2.099	3722	0.036
EMG RIGHT RA DF (%)	1.60	13.06	2.07	31.62	-1.818	3831	0.069
EMG LEFT EO DF (%)	4.22	45.35	6.70	27.83	-3.563	3154	0.000
EMG RIGHT EO DF (%)	5.24	83.70	5.19	38.19	-0.822	4217	0.411
EMG LEFT ES DF (%)	16.07	195.53	21.12	49.45	-3.411	3213	0.001
EMG RIGHT ES DF (%)	27.62	99.10	34.07	104.14	-2.305	3642	0.021
EMG LEFT GM DF (%)	13.55	94.24	16.74	87.87	-1.366	4006	0.172
EMG RIGHT GM DF (%)	8.68	125.27	8.70	64.32	-0.735	4251	0.462

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; DF – deceleration phase: finish point. Values display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

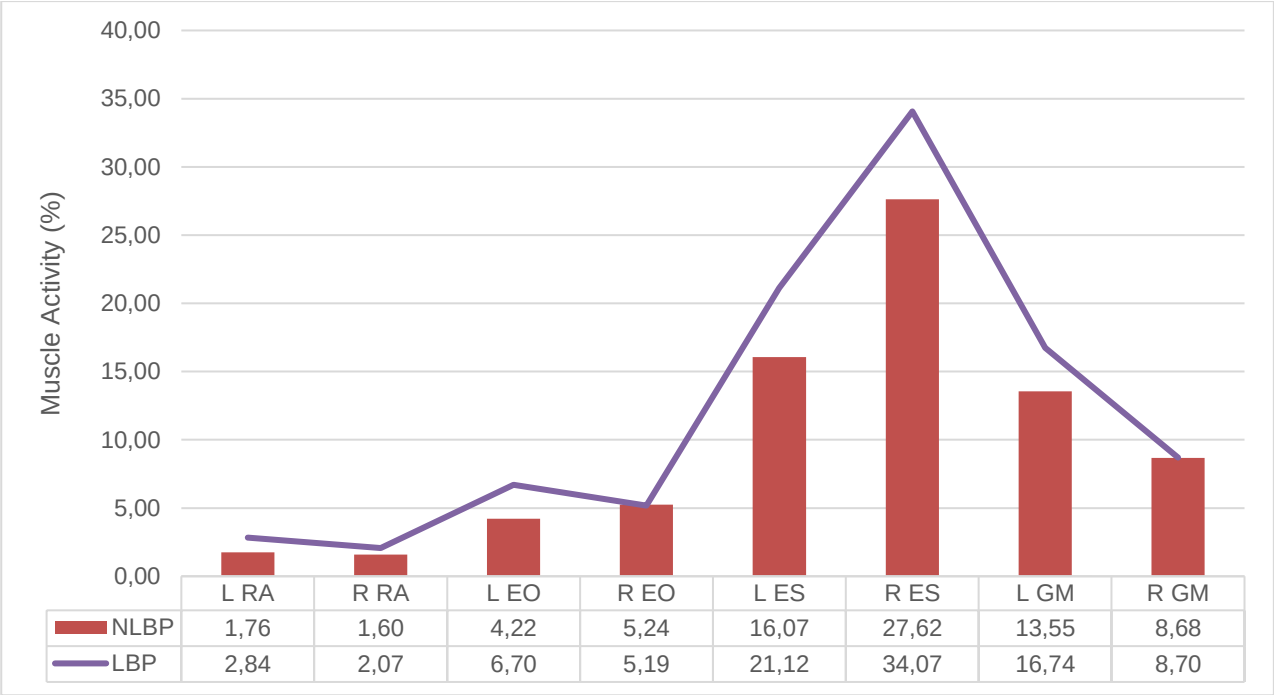


Figure 4. 19 Muscle Activation at the Finish Point of the Deceleration Phase during the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

NLBP – participants without lower back pain; LBP – participants with lower back pain; L – left; R – right; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; Values in the figure display the muscle activation (%) at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Description of the muscle activation at the Deceleration Phase: Final (DF)

The RA muscles in both groups indicated a limited level of muscle activity, but on the left more than on the right side, and in the LBP group more than in the NLBP group. The LBP group had higher levels of muscle activation in the EO muscles (see Table 4.19). Both groups displayed a higher muscle activation in the right ES compared to the left ES (Table 4.19). The LBP group had significantly-higher muscle activation levels in the left and right ES, compared to the NLBP group. The right GM displayed approximately the same muscle activation in both groups. Both groups had higher muscle activation levels in the left GM, as opposed to the right GM.

4.7 Muscle Activation Analysis: Sequences in EMG results

Each tennis player has an individual style in respect of motion and muscle activation during the tennis serve. On account of the unique and personal nature of the individual's serve, further analysis of the EMG data was carried out to examine the point of maximum muscle activation. Data was analysed to look at the maximum muscle activation during each phase of the serve (see Table 4.20). Each muscle was at its highest level of activation during that specific phase in the serve, and for that specific muscle.

Table 4. 20 Maximum Muscle Activation during Phases of the Tennis Serve for the NLBP (n=21) and LBP (n=12) Groups

	Phase of Serve	X^2 (1)	p
EMG LEFT RA	PC to AC	10.013	0.003
EMG LEFT RA	AC to DF	10.013	0.003
EMG RIGHT RA	PC to AC	4.537	0.066
EMG RIGHT RA	AC to DF	4.537	0.066
EMG LEFT EO	PL to PC	8.192	0.009
EMG LEFT EO	AC to DF	3.464	0.114
EMG RIGHT EO	PC to AC	9.429	0.002
EMG RIGHT EO	AC to DF	9.429	0.005
EMG LEFT ES	PL to PC	5.122	0.033
EMG LEFT ES	AC to DF	0.075	0.784
EMG LEFT ES	PC to AC	9.351	0.005
EMG RIGHT ES	PC to AC	1.310	0.538
EMG RIGHT ES	AC to DF	1.310	0.538
EMG LEFT GM	PL to PC	3.422	0.083
EMG LEFT GM	AC to DF	0.049	0.825
EMG LEFT GM	PL to PC	7.966	0.012

EMG RIGHT GM	PL to PC	1.515	0.274
EMG RIGHT GM	AC to DF	1.515	0.274

NLBP – participants without lower back pain; LBP – participants with lower back pain; EMG – electromyography; RA – rectus abdominis; EO – external oblique; ES – erector spinae; GM – gluteus maximus; PL – preparation phase: loading point; PC – preparation phase: cocking point; AC – acceleration phase: ball contact point; DF – deceleration phase: finish point. Values display the Chi-squared data (X^2) analysis comparing the participants with and without lower back pain, at that point during the tennis serve. The muscle activation data should be interpreted as if the tennis player were right dominant

Compared to the LBP group, the NLBP group displayed the greatest muscle activation of the left RA between the PC and AC phases (p=0.003) (Table 4.20), whilst the muscle activation of the LBP group was more likely to be higher in the left RA during the AC to DF phase (p=0.003). The left EO displayed more activity in the NLBP group during the PL and PC phases (p=0.009), while the right EO was significantly more active in the NLBP group during the PC to AC phase (p=0.002), and also in the LBP group during the AC to DF phase (p=0.005).

In the left ES muscle, the timing of the greatest muscle activation was during the PL to PC phase in the case of the NLBP group (p=0.033), and during the PC to AC phase in the case of the LBP group (p=0.005). Compared to the NLBP group, the LBP group displayed the greatest muscle activation of the left GM between the PL and PC phases (p=0.012). There were no significant differences between the timing of the highest muscle activation of the right RA, the right ES and the right GM between the two groups (Table 4.20).

4.8 Relationships between Variables Tested

Significant findings from the results were used in Pearson's bivariate correlation analysis, as presented in Table 4.21. During an initial correlation analysis, multicollinearity was found between the SEBT variables. For this reason, the SEBT variables was excluded from the correlation analysis. Active ROM (lateral flexion to the right) did also not fit well

(multicollinearity was found) into the models when this variable was combined with the other potential predictors. Thus, it was decided to exclude these variables from further correlation analysis and consideration in the logistic regression model. The kinematics and muscle activation results were included in the analysis.

A large number (n=34) of kinematic variables displayed a strong positive upslope linear relationship (r>0.70) when compared to the other kinematic variables. Furthermore, the co-linearity of the EMG variables displayed one moderate and two strong upslope linear relationships when compared to the other EMG variables (r>0.50; n=1 and r>0.70; n=2). Fourteen weak negative downslope linear relationships were found between the kinematics and EMG variables (r>-0.30) (see Table 4.21). The correlation coefficient results that were determined for the relationship between the kinematics and muscle activation variables were used for further testing. The predictors without co-linearity were used in the logistic regression model.

Table 4. 21 Correlation Coefficients between Variables for the NLBP (n=21) and LBP (n=12) Groups

	TRUNK INT EXT ROT PS	R HIP INT/EXT ROT PS	R HIP FLXN/EXT PS	L HIP FLXN/EXT PS	L HIP ABD/ADD PS	L HIP INT/EXT ROT PS	TRUNK INT EXT ROT PR	R HIP FLXN/EXT PR	L HIP INT/EXT ROT PR	L HIP FLXN/EXT PR	R HIP ABD/ADD PL	L HIP INT/EXT ROT PL	R HIP INT/EXT ROT PC	R HIP FLXN/EXT PC	L HIP INT/EXT ROT PC	R HIP FLXN/EXT AC1	L HIP INT/EXT ROT AC1	L HIP FLXN/EXT AC1	R HIP FLXN/EXT AC2	L HIP INT/EXT ROT AC2	L HIP FLXN/EXT AC2	TRUNK ABD/ADD DF	TRUNK INT EXT ROT DF	R HIP FLXN/EXT DF	L HIP ABD/ADD DF	L HIP INT/EXT ROT DF	L HIP FLXN/EXT DF	EMG5 L TXLX PS	EMG6 R TXLX PS	EMG8 R GM PS	EMG4 R EO PR	EMG1 L RA PL	EMG4 R EO PL	EMG6 R TXLX PL	EMG1 L RA PC	EMG2 R RA PC	EMG4 R EO AC1	EMG5 L TXLX AC1	EMG1 L RA AC2	EMG4 R EO AC2	EMG5 L TXLX AC2	EMG1 L RA DF	EMG2 R RA DF	EMG3 L EO DF	EMG5 L TXLX DF	EMG6 R TXLX DF
TRUNK INT EXT ROT PS	1	.851**	-0,065	-0,005	0,064	.793**	.913**	0,066	.845**	0,129	-.385**	.426**	.633**	-.258**	.565**	-.287**	.658**	0,018	-.169*	.687**	0,084	-0,11	.779**	0,038	.393**	.589**	0,008	-0,059	0,041	0,046	-0,129	-0,101	-0,114	0,038	-0,047	-0,025	-0,133	-0,116	-0,028	-0,084	-0,087	-0,133	-.153*	-0,057	-.175*	-0,035
R HIP INT/EXT ROT PS	**.851****	1	-0,089	-0,096	0,074	**.898****	**.805****	0,099	**.837****	**.212****	-.325**	**.458****	**.756****	-.295**	**.676****	-.262**	**.762****	0,067	-.169*	**.790****	0,123	0,033	**.698****	-0,051	**.437****	**.745****	0,033	0,076	-0,05	0,121	-0,131	-0,099	-.332**	0,068	-0,042	0,04	-.212**	-0,122	-0,1	-.195**	-0,049	-0,138	-.186**	0,007	-0,103	-0,016
R HIP FLXN/EXT PS	-0,065	-0,089	1	.331**	-0,132	-0,085	-0,021	.147*	-0,023	-0,04	-0,088	-.166*	-.167*	-.197**	-.224**	.236**	-0,139	0,094	.310**	-0,087	**.214****	-0,075	-0,022	.148*	-0,121	-0,061	0,032	-.164*	0,079	0,071	.166*	0,103	0,121	0,094	**.215****	.150*	0,054	-0,043	**.222****	0,078	-.140*	0,094	0,078	**.187****	-**.184****	-0,045
L HIP FLXN/EXT PS	-0,005	-0,096	**.331****	1	0,01	-.146*	-0,045	0,032	-0,107	0,033	-0,106	-.199**	-.164*	-.225**	-.250**	.149*	-0,09	-0,072	.191**	-0,089	-0,044	-0,101	0,002	-0,099	-.290**	-0,092	0,114	-.184**	0,088	0,076	.142*	-0,066	0,052	0,075	0,004	-0,064	0,068	0,078	.167*	0,124	-0,011	0,015	0,117	0,089	-.198**	0,109
L HIP ABD/ADD PS	0,064	0,074	-0,132	0,01	1	0,102	0,051	-0,012	0,097	0,016	-.290**	0,12	.244**	0,006	.298**	0,002	.220**	.146*	-0,008	.201**	.142*	.475**	0,103	-.145*	.552**	-0,004	-0,12	0,088	0,022	-0,108	0,031	0,079	0,053	0,094	0,084	0,03	.148*	-0,08	-0,071	0,087	-0,02	-.322**	-.483**	-.420**	-0,032	-0,083
L HIP INT/EXT ROT PS	**.793****	**.898****	-0,085	**-.146***	0,102	1	**.783****	0,07	**.894****	.170*	-.216**	.582**	**.714****	-.310**	**.745****	-.307**	**.820****	**.206****	-.216**	**.821****	**.224****	-0,002	**.658****	0,132	**.435****	**.798****	0,095	0,124	-0,052	0,009	-0,075	-0,011	-.269**	0,069	-0,029	0,079	-.208**	-0,046	-0,026	-.185**	0,022	-0,092	-.234**	-0,017	-0,023	-0,031
TRUNK INT EXT ROT PR	**.913****	**.805****	-0,021	-0,045	0,051	**.783****	1	.141*	**.868****	.312**	-.368**	.343**	.646**	-.299**	.567**	-.224**	.667**	0,137	-.142*	.659**	.163*	0,001	.727**	-0,004	.451**	.598**	-0,041	0,022	0,11	0,046	0,003	-0,048	-0,029	-0,03	0,04	-0,036	-0,05	-0,098	0,012	0	-0,096	-.157*	-.171*	-0,03	-.140*	-0,038
R HIP FLXN/EXT PR	0,066	0,099	**.147***	0,032	-0,012	0,07	**.141***	1	0,074	.699**	-.152*	-.144*	.242**	-0,139	0,104	0,057	0,096	.191**	0,06	0,073	.265**	.212**	0,037	0,012	0,135	-0,014	0,123	.218**	.157*	0,126	.186**	-.151*	-0,028	-0,079	0,015	-.189**	-0,01	-0,11	.145*	0,024	-.208**	0,026	0,116	0,025	-0,06
L HIP INT/EXT ROT PR	**.845****	**.837****	-0,023	-0,107	0,097	**.894****	**.868****	0,074	1	.154*	-.338**	.550**	.711**	-.293**	.749**	-.289**	.808**	0,08	-.194**	.803**	0,121	0,018	.625**	0,017	.483**	.664**	-0,046	0,016	-0,089	-0,011	-0,046	-0,043	-0,044	0,055	-0,036	0,043	-0,048	-0,038	0,013	-0,016	0,002	-.145*	-.236**	-0,023	-0,071	-0,082
L HIP FLXN/EXT PR	0,129	**.212****	-0,04	0,033	0,016	**.170***	**.312****	**.699****	**.154***	1	-0,105	-.157*	.273**	-0,08	.163*	0,012	0,135	.212**	0,003	0,079	.163*	.212**	.163*	-0,093	.174*	0,121	0,02	.157*	.234**	.215**	.312**	-0,008	0,015	-0,131	0,072	-.255**	0,051	-0,03	0,092	0,074	-0,094	-0,096	-0,123	.183*	0,001	0,08
R HIP ABD/ADD PL	**-.385****	**-.325****	-0,088	-0,106	**-.290****	**-.216****	**-.368****	**-.152***	**-.338****	-0,105	1	0,136	-.377**	0,003	-.272**	0,029	-.192**	0,047	0,022	-.246**	-0,056	-.311**	-.240**	.344**	-.421**	-0,041	.250**	0,103	-.153*	-0,03	0,014	0,011	-0,001	-0,005	-0,018	0,077	-0,046	0,115	-0,124	-0,099	.143*	.206**	.271**	0,081	.144*	0,029
L HIP INT/EXT ROT PL	**.426****	**.458****	**-.166***	**-.199****	0,12	**.582****	**.343****	**-.144***	**.550****	**-.157***	0,136	1	.495**	-0,055	.668**	-.185**	.585**	0,071	-0,12	.598**	-0,005	-.261**	.283**	.181*	.191**	.441**	-0,049	.225**	-.154*	-0,064	-0,044	-.224**	-.161*	0,005	-.144*	0,06	-0,094	0,033	-0,082	-0,127	0,115	-.169*	-.308**	-0,036	0,093	0,057
R HIP INT/EXT ROT PC	**.633****	**.756****	**-.167***	**-.164***	**.244****	**.714****	**.646****	**.242****	**.711****	**.273****	**-.377****	**.495****	1	-.313**	.767**	-0,136	.745**	.153*	-0,105	.733**	.157*	.239**	.524**	-0,117	.572**	.509**	0,057	.204**	-0,009	0,015	0,084	-.153*	-0,053	-0,081	-0,064	0,042	0,064	-.150*	0,035	0,044	-0,055	-.235**	-.356**	-0,002	-0,023	0,016
R HIP FLXN/EXT PC	**-.258****	**-.295****	**-.197****	**-.225****	0,006	**-.310****	**-.299****	-0,139	**-.293****	-0,08	0,003	-0,055	**-.313****	1	-0,084	.308**	-.367**	-0,075	.215**	-.260**	-0,102	-0,01	-.324**	-0,131	-0,088	-.224**	-.270**	-0,069	0,001	0,07	-0,002	0,068	0,032	-0,136	-0,096	-.283**	-0,082	0,068	-0,083	-0,057	0,057	-.164*	-.193**	-0,122	0,027	-0,029
L HIP INT/EXT ROT PC	**.565****	**.676****	**-.224****	**-.250****	**.298****	**.745****	**.567****	0,104	**.749****	**.163***	**-.272****	**.668****	**.767****	-0,084	1	-.234**	.831**	.176*	-.234**	.773**	0,117	0,136	.309**	-0,039	.573**	.479**	-0,138	.194**	-0,083	-0,046	0,019	-.156*	-0,072	0,023	-.161*	0,034	-0,008	-0,015	-0,039	-0,03	0,056	-.255**	-.391**	-0,05	0,045	0,023
R HIP FLXN/EXT AC1	**-.287****	**-.262****	**.236****	**.149***	0,002	**-.307****	**-.224****	0,057	**-.289****	0,012	0,029	**-.185****	-0,136	**.308****	**-.234****	1	-.308**	.192**	.904**	-.260**	0,113	0,025	-.290**	-.226**	-0,111	-.232**	-0,1	-0,063	0,115	0,058	.234**	-0,131	0,118	-.154*	-0,081	-0,116	0,023	-0,098	-0,014	0,024	-.145*	-0,1	0,026	0,066	-0,02	-0,135
L HIP INT/EXT ROT AC1	**.658****	**.762****	-0,139	-0,09	**.220****	**.820****	**.667****	0,096	**.808****	0,135	**-.192****	**.585****	**.745****	**-.367****	**.831****	**-.308****	1	.197**	-.266**	.915**	.161*	0,103	.485**	-0,035	.510**	.626**	0,041	.217**	-0,089	-0,019	-0,003	-0,103	-.144*	0,126	-0,094	.145*	-0,056	-0,045	-0,077	-0,082	0,027	-.158*	-.238**	-0,097	0,001	-0,03
L HIP FLXN/EXT AC1	0,018	0,067	0,094	-0,072	**.146***	**.206****	0,137	**.191****	0,08	**.212****	0,047	0,071	**.153***	-0,075	**.176***	**.192****	**.197****	1	.154*	.147*	.828**	.170*	-0,065	.142*	.251**	0,067	0,08	.268**	0,033	0,088	.205**	0,09	-0,074	-0,03	-0,014	-0,087	-0,057	-.154*	-0,106	-0,079	-.168*	0,07	0,034	0,003	0,008	-0,123
R HIP FLXN/EXT AC2	**-.169***	**-.169***	**.310****	**.191****	-0,008	**-.216****	**-.142***	0,06	**-.194****	0,003	0,022	-0,12	-0,105	**.215****	**-.234****	**.904****	**-.266****	**.154***	1	-.159*	.216**	-0,018	-0,125	-0,117	-0,137	-0,106	-0,114	-0,076	0,078	0,072	.161*	-0,133	0,055	-.175*	-0,013	-0,079	-0,005	-0,137	0,006	-0,012	-.151*	-0,072	0,065	0,055	-0,067	-0,098
L HIP INT/EXT ROT AC2	**.687****	**.790****	-0,087	-0,089	**.201****	**.821****	**.659****	0,073	**.803****	0,079	**-.246****	**.598****	**.733****	**-.260****	**.773****	**-.260****	**.915****	**.147***	**-.159***	1	.217**	0,115	.570**	-0,035	.521**	.718**	-0,043	.208**	-0,104	0,114	-0,008	-0,099	-.170*	0,06	-0,107	0,094	-0,139	-0,094	-0,105	-.155*	-0,005	-.163*	-.277**	-.144*	-0,029	-0,063
L HIP FLXN/EXT AC2	0,084	0,123	**.214****	-0,044	**.142***	**.224****	**.163***	**.265****	0,121	**.163***	-0,056	-0,005	**.157***	-0,102	0,117	0,113	**.161***	**.828****	**.216****	**.217****	1	.238**	0,04	.180*	.255**	.164*	0,031	.193**	-0,004	0,123	0,113	0,118	-0,093	-0,021	0,108	-0,071	-0,109	-.234**	-0,085	-0,134	-.225**	0,072	-0,002	-0,027	-0,051	-0,139
TRUNK ABD/ADD DF	-0,11	0,033	-0,075	-0,101	**.475****	-0,002	0,001	**.212****	0,018	**.212****	**-.311****	**-.261****	**.239****	-0,01	0,136	0,025	0,103	**.170***	-0,018	0,115	**.238****	1	-0,123	-.244**	.589**	-0,041	-0,118	.286**	.172*	0,068	.222**	0,074	0,124	0,104	.159*	0,016	.267**	-0,074	0,1	.221**	-0,004	-.247**	-.406**	-.302**	.143*	-0,035
TRUNK INT EXT ROT DF	**.779****	**.698****	-0,022	0,002	0,103	**.658****	**.727****	0,037	**.625****	**.163***	**-.240****	**.283****	**.524****	**-.324****	**.309****	**-.290****	**.485****	-0,065	-0,125	**.570****	0,04	-0,123	1	.145*	.315**	.698**	.206**	-0,088	0,111	0,064	-0,135	0,077	-0,083	-0,094	0,055	0,127	-0,089	-.151*	0,016	-0,071	-0,103	-0,107	-0,099	-0,083	-0,105	0,096
R HIP FLXN/EXT DF	0,038	-0,051	**.148***	-0,099	**-.145***	0,132	-0,004	0,012	0,017	-0,093	**.344****	**.181***	-0,117	-0,131	-0,039	**-.226****	-0,035	**.142***	-0,117	-0,035	**.180***	**-.244****	**.145***	1	-0,123	0,068	.416**	-0,013	0,074	-.161*	-0,057	0,081	0,083	.174*	0,037	0,082	-0,084	0,087	0,069	-0,099	0,066	0,055	-0,033	0,002	0,074	.236**
L HIP ABD/ADD DF	**.393****	**.437****	-0,121	**-.290****	**.552****	**.435****	**.451****	0,135	**.483****	**.174***	**-.421****	**.191****	**.572****	-0,088	**.573****	-0,111	**.510****	**.251****	-0,137	**.521****	**.255****	**.589****	**.315****	-0,123	1	.256**	-0,104	.219**	.220**	0,044	0,11	0,034	0,125	0,041	-0,089	0,014	.144*	-0,117	-0,074	0,12	-0,045	-.326**	-.443**	-.376**	0,022	-0,086
L HIP INT/EXT ROT DF	**.589****	**.745****	-0,061	-0,092	-0,004	**.798****	**.598****	-0,014	**.664****	0,121	-0,041	**.441****	**.509****	**-.224****	**.479****	**-.232****	**.626****	0,067	-0,106	**.718****	**.164***	-0,041	**.698****	0,068	**.256****	1	-0,019	.169*	-0,12	0,133	-0,109	.153*	-.292**	-0,024	0,076	0,063	-.304**	-0,118	-0,07	-.287**	-0,051	-0,016	-0,109	-0,022	-0,06	-0,025
L HIP FLXN/EXT DF	0,008	0,033	0,032	0,114	-0,12	0,095	-0,041	0,123	-0,046	0,02	**.250****	-0,049	0,057	**-.270****	-0,138	-0,1	0,041	0,08	-0,114	-0,043	0,031	-0,118	**.206****	**.416****	-0,104	-0,019	1	-0,069	.171*	-.161*	0,017	0,028	0,051	0,098	0,036	.211**	0,05	0,116	.143*	0,032	0,111	0,041	0,021	0,017	0,067	.186**
EMG5 L TXLX PS	-0,059	0,076	**-.164***	**-.184****	0,088	0,124	0,022	**.218****	0,016	**.157***	0,103	**.225****	**.204****	-0,069	**.194****	-0,063	**.217****	**.268****	-0,076	**.208****	**.193****	**.286****	-0,088	-0,013	**.219****	**.169***	-0,069	1	.156*	0,106	.190**	-0,078	-.191**	0,127	0,009	-0,1	0,001	0,005	0,024	-0,033	0,047	-0,003	-.146*	-0,13	.242**	0,088
EMG6 R TXLX PS	0,041	-0,05	0,079	0,088	0,022	-0,052	0,11	**.157***	-0,089	**.234****	**-.153***	**-.154***	-0,009	0,001	-0,083	0,115	-0,089	0,033	0,078	-0,104	-0,004	**.172***	0,111	0,074	**.220****	-0,12	**.171***	**.156***	1	.170*	.272**	0,001	.216**	-0,139	0,033	-.178*	.248**	0,106	.320**	.248**	0,09	-.248**	-.204**	-0,019	.223**	.435**
EMG8 R GM PS	0,046	0,121	0,071	0,076	-0,108	0,009	0,046	0,126	-0,011	**.215****	-0,03	-0,064	0,015	0,07	-0,046	0,058	-0,019	0,088	0,072	0,114	0,123	0,068	0,064	**-.161***	0,044	0,133	**-.161***	0,106	**.170***	1	-0,033	-0,099	-.142*	-0,08	-0,071	-.187**	-0,108	-0,094	-0,09	-0,123	-0,077	-0,049	0,002	-0,007	-0,066	-0,053
EMG4 R EO PR	-0,129	-0,131	**.166***	**.142***	0,031	-0,075	0,003	**.186****	-0,046	**.312****	0,014	-0,044	0,084	-0,002	0,019	**.234****	-0,003	**.205****	**.161***	-0,008	0,113	**.222****	-0,135	-0,057	0,11	-0,109	0,017	**.190****	**.272****	-0,033	1	0,082	.395**	-0,093	0,058	0,015	.287**	0,037	0,127	.272**	0,001	-.269**	-.205**	0,116	-0,007	0,084
EMG1 L RA PL	-0,101	-0,099	0,103	-0,066	0,079	-0,011	-0,048	**.151***	-0,043	-0,008	0,011	**-.224****	**-.153***	0,068	**-.156***	-0,131	-0,103	0,09	-0,133	-0,099	0,118	0,074	0,077	0,081	0,034	**.153***	0,028	-0,078	0,001	-0,099	0,082	1	.241**	-.135	.468**	0,08	0,107	-0,087	0,042	0,079	-0,067	0,116	-0,039	-0,033	-0,101	-0,058
EMG4 R EO PL	-0,114	**-.332****	0,121	0,052	0,053	**-.269****	-0,029	-0,028	-0,044	0,015	-0,001	**-.161***	-0,053	0,032	-0,072	0,118	**-.144***	-0,074	0,055	**-.170***	-0,093	0,124	-0,083	0,083	0,125	**-.292****	0,051	**-.191****	**.216****	**-.142***	**.395****	**.241****	1	-0,132	0,093	0,047	.481**	0,018	.185**	.470**	0	-.193**	-.152*	0,043	0,015	0,075
EMG6 R TXLX PL	0,038	0,068	0,094	0,075	0,094	0,069	-0,03	-0,079	0,055	-0,131	-0,005	0,005	-0,081	-0,136	0,023	**-.154***	0,126	-0,03	**-.175***	0,06	-0,021	0,104	-0,094	**.174***	0,041	-0,024	0,098	0,127	-0,139	-0,08	-0,093	-0,135	-0,132	1	-.205**	0,06	-.218**	0,043	-.225**	-.215**	0,036	-0,064	-0,057	-.154*	-0,044	-0,052
EMG1 L RA PC	-0,047	-0,042	**.215****	0,004	0,084	-0,029	0,04	0,015	-0,036	0,072	-0,018	**-.144***	-0,064	-0,096	**-.161***	-0,081	-0,094	-0,014	-0,013	-0,107	0,108	**.159***	0,055	0,037	-0,089	0,076	0,036	0,009	0,033	-0,071	0,058	**.468****	0,093	**-.205****	1	.192**	.204**	0,004	.244**	.174*	-0,003	0,092	-0,096	0,046	**-.146***	0,016
EMG2 R RA PC	-0,025	0,04	**.150***	-0,064	0,03	0,079	-0,036	**-.189****	0,043	**-.255****	0,077	0,06	0,042	**-.283****	0,034	-0,116	**.145***	-0,087	-0,079	0,094	-0,071	0,016	0,127	0,082	0,014	0,063	**.211****	-0,1	**-.178***	**-.187****	0,015	0,08	0,047	0,06	**.192****	1	0,097	0,024	-0,112	0,051	0,05	0,008	0,046	-0,002	0,027	-0,132
EMG4 R EO AC1	-0,133	**-.212****	0,054	0,068	**.148***	**-.208****	-0,05	-0,01	-0,048	0,051	-0,046	-0,094	0,064	-0,082	-0,008	0,023	-0,056	-0,057	-0,005	-0,139	-0,109	**.267****	-0,089	-0,084	**.144***	**-.304****	0,05	0,001	**.248****	-0,108	**.287****	0,107	**.481****	**-.218****	**.204****	0,097	1	-0,017	.464**	.903**	0,025	-.186**	-.199**	0,02	0,116	.218**
EMG5 L TXLX AC1	-0,116	-0,122	-0,043	0,078	-0,08	-0,046	-0,098	-0,11	-0,038	-0,03	0,115	0,033	**-.150***	0,068	-0,015	-0,098	-0,045	**-.154***	-0,137	-0,094	**-.234****	-0,074	**-.151***	0,087	-0,117	-0,118	0,116	0,005	0,106	-0,094	0,037	-0,087	0,018	0,043	0,004	0,024	-0,017	1	0,031	0,062	.914**	-0,042	-0,082	0,033	0,09	0,129
EMG1 L RA AC2	-0,028	-0,1	**.222****	**.167***	-0,071	-0,026	0,012	**.145***	0,013	0,092	-0,124	-0,082	0,035	-0,083	-0,039	-0,014	-0,077	-0,106	0,006	-0,105	-0,085	0,1	0,016	0,069	-0,074	-0,07	**.143***	0,024	**.320****	-0,09	0,127	0,042	**.185****	**-.225****	**.244****	-0,112	**.464****	0,031	1	.494**	-0,006	-0,015	-0,112	.193**	.235**	.406**
EMG4 R EO AC2	-0,084	**-.195****	0,078	0,124	0,087	**-.185****	0	0,024	-0,016	0,074	-0,099	-0,127	0,044	-0,057	-0,03	0,024	-0,082	-0,079	-0,012	**-.155***	-0,134	**.221****	-0,071	-0,099	0,12	**-.287****	0,032	-0,033	**.248****	-0,123	**.272****	0,079	**.470****	**-.215****	**.174***	0,051	**.903****	0,062	**.494****	1	0,034	-.172*	-.172*	0,065	0,108	.205**
EMG5 L TXLX AC2	-0,087	-0,049	**-.140***	-0,011	-0,02	0,022	-0,096	**-.208****	0,002	-0,094	**.143***	0,115	-0,055	0,057	0,056	**-.145***	0,027	**-.168***	**-.151***	-0,005	**-.225****	-0,004	-0,103	0,066	-0,045	-0,051	0,111	0,047	0,09	-0,077	0,001	-0,067	0	0,036	-0,003	0,05	0,025	**.914****	-0,006	0,034	1	-0,066	-0,126	-0,014	0,134	.183**
EMG1 L RA DF	-0,133	-0,138	0,094	0,015	**-.322****	-0,092	**-.157***	0,026	**-.145***	-0,096	**.206****	**-.169***	**-.235****	**-.164***	**-.255****	-0,1	**-.158***	0,07	-0,072	**-.163***	0,072	**-.247****	-0,107	0,055	**-.326****	-0,016	0,041	-0,003	**-.248****	-0,049	**-.269****	0,116	**-.193****	-0,064	0,092	0,008	**-.186****	-0,042	-0,015	**-.172***	-0,066	1	.648**	.328**	-0,001	-0,095
EMG2 R RA DF	**-.153***	**-.186****	0,078	0,117	**-.483****	**-.234****	**-.171***	-0,066	**-.236****	-0,123	**.271****	**-.308****	**-.356****	**-.193****	**-.391****	0,026	**-.238****	0,034	0,065	**-.277****	-0,002	**-.406****	-0,099	-0,033	**-.443****	-0,109	0,021	**-.146***	**-.204****	0,002	**-.205****	-0,039	**-.152***	-0,057	-0,096	0,046	**-.199****	-0,082	-0,112	**-.172***	-0,126	**.648****	1	**.360****	-0,036	-0,06
EMG3 L EO DF	-0,057	0,007	**.187****	0,089	**-.420****	-0,017	-0,03	0,115	-0,023	**.183***	0,081	-0,036	-0,002	-0,122	-0,05	0,066	-0,097	0,003	0,055	**-.144***	-0,027	**-.302****	-0,083	0,002	**-.376****	-0,022	0,017	-0,13	-0,019	-0,007	0,116	-0,033	0,043	**-.154***	0,046	-0,002	0,02	0,033	**.193****	0,065	-0,014	**.328****	**.360****	1	0,084	.260**
EMG5 L TXLX DF	**-.175***	-0,103	**-.184****	**-.198****	-0,032	-0,023	**-.140***	0,025	-0,071	0,001	**.144***	0,093	-0,023	0,027	0,045	-0,02	0,001	0,008	-0,067	-0,029	-0,051	**.143***	-0,105	0,074	0,022	-0,06	0,067	**.242****	**.223****	-0,066	-0,007	-0,101	0,015	-0,044	**-.146***	0,027	0,116	0,09	**.235****	0,108	0,134	-0,001	-0,036	0,084	1	.327**
EMG6 R TXLX DF	-0,035	-0,016	-0,045	0,109	-0,083	-0,031	-0,038	-0,06	-0,082	0,08	0,029	0,057	0,016	-0,029	0,023	-0,135	-0,03	-0,123	-0,098	-0,063	-0,139	-0,035	0,096	**.236****	-0,086	-0,025	**.186****	0,088	**.435****	-0,053	0,084	-0,058	0,075	-0,052	0,016	-0,132	**.218****	0,129	**.406****	**.205****	**.183****	-0,095	-0,06	**.260****	**.327****	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

ROM Lx Lat Flexion R – active range of motion, lumbar lateral flexion to the right; L – left side; R – right side; ABD/ADD – abduction-adduction motion; INT/EXT ROT – internal-external rotation motion; FLXN/EXT – flexion-extension motion; PS – preparation phase: start of serve; PR – preparation phase: ball release serve; PL – preparation phase: loading point of serve; AC1 – acceleration phase: ball contact serve; AC2 – acceleration phase: maximum shoulder abduction serve; DF – deceleration phase: finish of serve; EO – external oblique; ES – erector spinae; GM – gluteus maximus; LAM – left anteromedial reach; LA – left anterior reach; RAL – right anterolateral reach; LPL – left posterolateral reach; RP – right posterior reach; Values display the correlation (r=) between two variables. The correlation data should be interpreted as if the tennis player were right dominant

4.9 Logistic Regression

Kinematic and muscle activation results that did not display co-linearity were included in a binary logistic regression model. The regression model was used to determine which of the results were the strongest at predicting LBP status. Table 4.22 presents the Forward Stepwise (Wald) method for the predictors explored. Model 16 was used as it accounts for 89.9% of the variance in the groupings.

Table 4. 22 Model Summary of the Forward Stepwise (Wald) Method for the NLBP (n=21) and LBP (n=12) Groups

Step	-2 Log likelihood	Cox and Snell R Square	Nagelkerke R Square
1	202.362	0.251	0.344
2	181.522	0.326	0.446
3	164.561	0.381	0.522
4	145.025	0.439	0.601
5	130.082	0.48	0.657
6	119.503	0.507	0.694
7	110.669	0.529	0.724
8	112.948	0.523	0.716
9	96.265	0.562	0.769
10	85.733	0.584	0.8
11	75.036	0.606	0.83
12	67.6	0.621	0.85
13	70.11	0.616	0.843
14	59.799	0.635	0.87
15	52.933	0.648	0.887
16	47.997	0.656	0.899

NLBP – participants without lower back pain; LBP – participants with lower back pain

Table 4.23, displays the accuracy in the classifications of model 16, which explains 96% of the overall predictions correctly.

Table 4. 23 Classification Table for Model 16 for the NLBP (n=21) and LBP (n=12) Groups

Observed		Predicted Group		Percentage Correct (%)
		NLBP (n=21)	LBP (n=12)	
Model 16	NLBP Group	123	3	97.6
	LBP Group	5	67	93.1
Overall Percentage (%)				96

NLBP – participants without lower back pain; LBP – participants with lower back pain

During the logistic regression analysis, the LBP group was coded as two and the NLBP group as one. In Table 4.24, the regression coefficients (B), which were found to be negative, indicate that an increase in these would be linked to membership of the NLBP group, while positive variables would indicate the opposite.

Table 4. 24 Model 16 – Logistic Regression Results for the NLBP (n=21) and LBP (n=12) Groups

	B	S.E.	Wald	df	Sig.	Exp(B)	OR
LEFT HIP FLXN/EXT PS	-0.288	0.08	12.995	1	0.001	0.75	0.750
RIGHT HIP FLXN/EXT PR	-0.478	0.115	17.262	1	0.001	0.62	0.620
LEFT HIP INT/EXT ROT PR	0.341	0.089	14.606	1	0.001	1.406	1.406
LEFT HIP INT/EXT ROT PL	-0.144	0.071	4.132	1	0.042	0.866	0.866
LEFT HIP ABD/ADD DF	-0.63	0.165	14.521	1	0.001	0.533	0.533
LEFT HIP INT/EXT ROT DF	0.224	0.069	10.686	1	0.001	1.252	1.252
LEFT HIP FLXN/EXT DF	0.238	0.06	15.574	1	0.001	1.269	1.269
EMG1 LEFT RA PL	-0.439	0.112	15.23	1	0.001	0.645	0.645
EMG4 RIGHT EO PL	0.096	0.033	8.708	1	0.003	1.101	1.101
EMG2 RIGHT RA DF	0.43	0.164	6.851	1	0.009	1.537	1.537

NLBP – participants without lower back pain; LBP – participants with lower back pain. FLXN/EXT – flexion-extension motion; INT/EXT ROT – internal-external rotation motion; ABD/ADD – abduction-adduction motion; PS – preparation phase: start of serve; PR – preparation phase: ball release point of serve; PL – preparation phase: loading point of serve; DF – deceleration phase: finish point; EMG – electromyography; RA – rectus abdominis; EO – external oblique. NLBP was coded as 1 and LBP was coded as 2, thus a negative coefficient (B) would describe a lean towards NLBP and a positive lean towards LBP

For each increase in left hip flexion motion (degrees) at the PS phase, there is a 25% less likelihood of experiencing LBP (OR=0.75) (see Table 4.24). For every degree increase in the flexion of the right hip at the PR phase, the odds of having lower back pain decrease by 38% (OR=0.62). With each degree of decrease in the external rotation of the left hip at the PR phase, there is a 40.60% greater likelihood of being classified into the LBP group (OR=1.406). Each degree of increase in the external rotation of the left hip at the PL phase is associated with a 13.4% less likelihood of being classified into the LBP group (OR=0.866). At the DF phase, for every degree of decrease in the adduction motion of the left hip, there is a 46.7% lesser likelihood of being classified into the LBP group (OR=0.533). For every degree of increase in the internal rotation of the left hip at the DF phase, the odds of having lower back pain increase by 25.20% (OR=1.252). With each degree of increase in the flexion of the left hip at the DF, there is a 26.90% greater likelihood of being classified into the LBP group (OR=1.269). For each percentage increase in the left RA muscle activity at the PL phase, there is a 35.50% less likelihood of experiencing LBP (OR=0.645). Each percentage decrease in the right EO muscle activation at the PL phase is associated with a 10.1% greater likelihood of being classified into the LBP group (OR=1.101). At the DF phase, for every percentage increase in the activation of the right RA muscle, there is a 53.7% greater likelihood of being classified into the LBP group (OR=1.537) (see Table 4.24).

4.10 Conclusion of Results

The eight sections interpreted in the results chapter covered demographic history, behavioural and physical variables that were tested between the two groups. The correlations between the relevant variables were also interpreted. A segment of the results is in comparison to what is currently known in the literature, whilst a further segment is in contention in respect of what is currently known. Further findings in the results chapter may

give some new insights into the differences between the tennis players with and without lower back pain. Leading on from the results chapter, a discussion as to why these findings could be relevant now follows.

CHAPTER 5: DISCUSSION

5.1 Introduction

Variables that may affect the serve in tennis players with and without lower back pain formed the basis of the study objectives. From the literature review intrinsic and extrinsic risk factors were selected that could have an effect on the LBP status of an adolescent tennis player. The results, aligned with the objectives, were distinctly presented in the previous chapter. The results will now be discussed in the following sections: participants, active ROM, dynamic lower limb balance, and the tennis serve. The tennis serve section includes the kinematics and muscle activation during the serve. This section concludes with a discussion on the relationships between the variables and identifies the strongest predicting variable for lower back pain.

5.2 Participants

The sample sizes for the LBP (n=12) and the NLBP (n=21) groups were relatively unbalanced. In this study, 36.4% of this sample of adolescent tennis players experienced lower back pain (sample n=33 of the population group n=138). This supports what is known in the literature, as a hypothesis to the effect, that by the age of 18, 48% of adolescents will have experienced lower back pain (Andersen, Wedderkopp and Leboeuf-Yde, 2006). Further literature reports indicate that approximately 20% of adolescent tennis players suffer from lower back pain (Pluim *et al.*, 2006; Hjelm, Werner and Renstrom, 2012). Therefore, the findings for the sample in this study are similar to what has been found in other studies. Thus, these findings could be interpreted as an acceptable representation of the North Gauteng adolescent tennis players.

No significant differences in terms of age, sex, height, BMI and years of experience (playing tennis) were found between the two groups. This indicates that the two groups are similar in terms of these variables. There is no statistical association between upper limb dominance and group classification for the two groups. The majority of the players in both groups were found to be dominant in their right upper limb.

For the lower limbs, the difference in the proportion of left dominant compared to right dominant players in each of the two groups (p=0.015) was found to be significant. The LBP group had proportionally more tennis players with left lower limb dominance. The dominance of lower limbs is rarely a factor that coaches consider when looking at technique during the tennis serve. Young *et al.* (2014) reported a two-degree difference in total hip flexion ROM between the dominant and non-dominant side of junior female tennis players. It was for this reason that the results of this study were analysed in terms of dominance. Limb dominance could indicate the importance of individualised training and strengthening programmes. Coaches need to look at the individual and his/her specific profile.

The current study shows that the LBP group spend an average of 3.5 hours more on the court (mean=8.5 hours) than the NLBP group (mean=5 hours). Although this difference is not significant (p=0.118), it does show that the LBP group spend more than six hours per week playing tennis. Hjelm *et al*. (2012) report that a previous injury to the back and the practice of playing tennis more than six hours per week have been identified as risk factors for back pain (Hjelm, Werner and Renstrom, 2012). This suggests that the fact that the LBP group spends more than six hours playing tennis puts them at risk for injury.

The lower back pain group reported a low to moderate intensity of lower back pain (3.38 to 5.33/10 VAS), over a long period of time (one to six months), that was exacerbated by playing tennis. This indicates that the chronic lower back pain symptoms that the LBP group experiences are aggravated by their sport.

Fewer injuries have been reported by adolescents when playing on clay courts than by those playing on hard courts (Abrams, Renstrom and Safran, 2012; Malliou, 2015). There was a significant association between the number of hours played on a hard court and the presence of lower back pain ($p=0.052$). Unfortunately, only a limited number of participants make use of grass- or clay-court surfaces during practise or play. Thus, it was not viable in the case of this sample to determine whether the surface type can have an influence on the participants' lower back pain status. These results suggest that more attention should be given to the number of hours spent on the court rather than to the court surface itself.

No significant difference was found between the two groups for the number of hours per week spent on singles matches, doubles matches, tennis practise, and doing other exercises. There was, however, a significant difference between the groups in terms of the number of hours per week spent playing other sports ($p=0.045$). The NLBP group spent more time (difference in mean of 2.06±0.5hours) participating in other types of sport compared to the LBP group. The evidence suggests that it might be beneficial for adolescent tennis players to participate in other forms of sport. By participating in other forms of sport, the tennis player may reach an improved equilibrium in his/her training regime.

The majority of participants reported that their hand grip was taught to them by their coach. According to the head coach at the North Gauteng Tennis Club, the semi-western is the preferred type of hand grip initially taught to the adolescent tennis players. The LBP group (median=66.67%) makes more use than the NLBP group (median=23.81%) of the semi-western hand grip. However, this was not considered to be a significant variable in the identification of players with and without lower back pain (p=0.083).

Campbell *et al.* (2013) reported that both the kick (topspin) and flat serve can be characterised by high lumbar loading conditions. In this study, 83.81% of the NLBP group and 92.50% of the LBP group made use of the flat and topspin (kick) types of serve. This indicates that both groups experience high load conditions in their lumbar spine while executing a tennis serve.

5.4 Active Range of Motion

Active ROM testing is used widely in injury-prevention programmes, along with other objective assessments of the joints. Even though only one significant difference was found in the active ROM between the two groups, the LBP group indicated lower levels in the majority of the ROM tests. These results are equivalent to what can be seen in the general population, namely that people with lower back pain experience a reduction in lumbar ROM (Laird et al 2014). Hjelm *et al*. (2012) reported that tennis players with back pain presented with less ROM in many joints, although the results were also not significant (Hjelm, Werner and Renstrom, 2012). This suggests that active ROM, in conjunction with other testing modalities, is still a reasonably good measurement tool to use. Active ROM could indicate

differences when comparing the right to the left sides, as well as in comparing the results with those of other tennis players.

The only significant difference that was found in the case of active ROM testing was for lumbar lateral flexion. The NLBP group displayed more lumbar lateral flexion to the right. This indicates that the NLBP players have more active range available for lumbar lateral flexion to the right during the tennis serve. In contrast, the LBP players made use of more lumbar lateral flexion and rotation kinematics during various phases of the tennis serve. Even though the NLBP group displayed more available active ROM, the LBP group displayed a larger range of movement during the tennis serve. The difference in active ROM of the lumbar spine, tested in standing and during the tennis serve, suggests that there is a discrepancy in the kinetic control between the two groups. It is possible that the LBP group is unable to control the movement through the range and this may result in translation at the level in question. This has been explained in the literature as a movement dysfunction (Comerford and Mottram, 2012).

When the hip and knee are flexed at a 90° angle, the normal ranges for the internal and external rotation of the hip is between 42° and 50° (Roach and Miles, 1991; Levangie and Norkin, 2011; Han *et al.*, 2015). The active ROM in the mean rotation of the hips is on the lower spectrum of normal values (internal rotational mean=41.88±29.5°; external rotational mean=35.5±22°). In research, the combined normal ROM for the internal and external rotation of the hip is approximately 90° (Roach and Miles, 1991; Levangie and Norkin, 2011; Han *et al.*, 2015). For this study, the mean combined ROM was found to be 77.38±51.5°. During a tennis match, the serve makes use of hip rotation for precision playing and

performance of motion. The difference in rotational active ROM testing between the two groups proved to be insignificant. However, the active ROM findings in tennis players could point to possible muscle restrictions and imbalances around their hip joints.

Analyses suggest that tennis players may generally experience an increase in internal rotation and a decrease in external rotation at the hip joints (mean difference of 6.38°). These findings have been reported for professional female tennis players in the relevant literature (Young *et al.*, 2014). However, no association was made between the active ROM of the hip and lower back pain. The results of this study might suggest that the hip joint undergoes the same rotational forces as the shoulder joint. The forces in the shoulder result in a glenohumeral internal rotation deficit, or a GIRD type of dysfunction.

Hip rotation angles have an effect on pelvic tilt, and therefore on lumbar positioning. For example, if the hips are maximally rotated externally, the pelvis will be posteriorly tilted and the lumbar spine flexed. This could have an effect on the kinematics and in turn, lower back pain status. All the same, the presence of an internal or external rotational deficit of the hip is an interesting argument that could point to prospective research endeavours. However, caution is needed when interpreting group results as an individual assessment of each player's hip ROM values is needed in order to make accurate assumptions.

5.3 Dynamic Lower Limb Balance Test

Results from the SEBT indicate that the LBP group has a greater reach in all directions. Significant differences were found in the left anteromedial ($p=0.011$) and left anterior ($p=0.047$), right anterolateral ($p=0.010$), left posterolateral ($p=0.047$) and right posterior

(p=0.041) reach directions. These results suggest that the LBP group show a better dynamic balance in their lower limbs compared to the NLBP group. It is possible that the LBP group make use of fixation compensatory mechanisms (Comerford and Mottram, 2012), which results in better dynamic balance strategies. Even though the LBP group displayed better dynamic lower limb balance strategies, they did not display better control through range of motion during the tennis serve, especially during the DF phase. It has been reported that the control of a collapse of the lower limb could be independent of the control of posture and balance (Winter, Patla and Frank, 1990).

Contrary to these findings, a study by Ganesh *et al*. (2015) of an adult inactive population reported that when compared to a control group, their chronic lower back pain group demonstrated a significant reduction in reach lengths in all the directions, except the posterior one (Ganesh, Chhabra and Mrityunjay, 2015). The results could suggest that balance strategies in adolescents might not be the same when compared to an adult or post-puberty population.

The hours spent participating in other types of sport differed between the two groups (p=0.045). It is worth noting that participation of the selected tennis players in other types of sport, could have affected the dynamic lower limb balance performance of the two groups.

Furthermore, it is possible that the SEBT was not accurately executed by the adolescent tennis players. Since none of the tennis players had completed the SEBT prior to the data collection phase of this study, and, as discussed in the methodology of the literature, each participant was given only three practice trials, and was asked whether he/she felt

comfortable to commence the test, it is possible that the LBP group exhibited a quicker "learning effect" in terms of the SEBT than the NLBP group.

Furthermore, time of day may influence dynamic postural control (Gribble, Tucker and White, 2007). Testing was not done at the same time of day or on the same day. The reason for this was the amount of time that it takes to conduct the physical testing (approximately 90 to 120 minutes per participant). Apart from that, it was difficult to stipulate a time to carry out the tests in that it had to suit all parties involved (parents, coaches, participants and the researcher).

Concluding from the abovementioned discussion points, the results from this study indicate that the SEBT might not be useful for identifying reach deficits in elite adolescent tennis players with and without lower back pain. Thus, the SEBT may not be an effective tool for measuring LBP risk in adolescent tennis players, a topic that would require further research analysis.

5.5 Tennis Serve: Kinematics and Muscle Activity

From the results, the two groups were found to adopt different kinematic and muscle activation strategies in order to master the technique of the perfect serve. The difficulty of the serve movement results from the summation of forces – from the ground up through the kinetic chain, and out into the ball (Kovacs and Ellenbecker, 2011c). Effective tennis servers use the kinetic chain via a muscle activation synchrony of the coordinated lower extremity muscles that provides a stable base for the trunk on which to rotate, extend and flex, while also helping to produce force (Kibler and Safran, 2005; Kovacs, Ellenbecker and Kibler,

2010). Each chain in the link needs to be synchronised in order to achieve an optimal outcome. If the chain is not synchronised, the tennis player may use adaptation strategies to attain the optimal outcome.

The results in this study can give us an in-depth view of the kinematics and muscle activation in the lower quarter during the tennis serve. Further discussion includes assessing the differences between the participants with and without lower back pain in terms of their adaptations to pain, the differences in their muscle activation, and the possibility of uncontrolled movement. These findings could shed some light on the synchrony needed.

Tennis players make use of force couples to effectively transfer the ball over the net. Force coupling between the global stabiliser and the global mobiliser muscles creates effective movement. However, pain and/or dysfunction may cause chronic adaptations to motor control in the body (Comerford and Mottram, 2012). This results in an uncontrolled movement of a segment and, if not addressed, may lead to chronic symptoms. Motor control dysfunction has been explained by Gibbons and Comerford (2001) to demonstrate delayed timing/recruitment; muscle shortening/lengthening; poor recruitment or control of motor units; and myofascial shortening/restriction. Shortening can be described as a decrease in extensibility of the mobiliser muscles and myofascial tissue (Comerford and Mottram, 2012).

Hodges and Tucker (2011) indicate that adaptations to pain involve the following changes: redistribution of activity within and between the muscles; changes in mechanical behaviour such as modified movement and stiffness; adaptations lead to protection from further pain or injury, or from threatened pain or injury; these are not explained in terms of simple

changes in excitability, but involves changes at multiple levels of the motor system. Furthermore, these changes may be complementary, supplementary, or competitive; lastly, pain has short-term benefits, but its consequences are potentially long-term owing to factors such as increased load, decreased movement, and decreased variability (Hodges and Tucker, 2011).

Adaptations to pain could lead to pain inhibition. Pain inhibition leads to the reduced functioning and coordination of the stability muscles in the lower back (Ganesh, Chhabra and Mrityunjay, 2015). These constructs should be kept in mind when discussing the differences between the two groups.

Results of the tennis serve will be discussed in two sections, namely the interpretation of the kinematics and muscle activation; and a discussion on the differences in kinematics and muscle activation in the two groups.

5.5.1 Preparation Phase: Start (PS)

Interpretation of Kinematics and Muscle Activation of the NLBP Group

For the NLBP group the starting position is similar to what has been reported by Kovacs and Ellenbecker (2011). This hunched forward positioning could be explained as the point when the player has the ball in contact with the racquet, in preparation to aim for the target on the other side of the net (see Figure 5.1).

In both groups, the right hip is flexed more than the left. However, the left hip is internally rotated to a greater extent than the right. The differences seen in the flexion and internal rotation of the hips could indicate an antero-lateral tilt to the pelvis at the starting point. The tilt could be an indication of weight transfer within the base of support – the start of force generation.

The anterior trunk muscles are activated with a minuscule higher level of activation on the left as opposed to the right, especially in the case of the left EO. The posterior trunk muscles display higher muscle activation levels on the right compared to the left. In the study by Chow *et al.* (2003), they described a small degree of muscle activation in the left internal oblique and bilateral ES at the start of the serve. When combining the results of the two studies we can report that the left internal oblique and EO, together with the posterior trunk muscles (ES and GM) could be activating as a stabilising force couple system. In static postures force couples are used to control translation (Comerford and Mottram, 2012).

The right ES muscle presents with the largest muscle activation at this point. The left ES and bilateral GM, could be forming a force couple for the right ES. On the other hand, the bilateral RA, and the right EO could perform as a force couple for the left EO muscle. Force couples are described by Gibbons and Comerford (2001a). The right ES muscle will initiate the start of movement in the spine in order to extend, to flex laterally, and to rotate to the right.



Figure 5. 1 Preparation Phase: Start (PS)

Discussion of Differences in Kinematics and Muscle Activation Between the Two Groups

The start phase demonstrates the individual style of the tennis player. However, the goal remains to align the body to best use the ground reaction forces throughout the remainder of the serve (Kovacs and Ellenbecker, 2011c). The LBP group displayed greater rotational motions at the starting point in the internal rotation of the trunk ($p=0.017$), the internal rotation of the right hip ($p=0.003$), and the internal rotation ($p=0.002$) as well as adduction ($p=0.003$) of the left hip.

The NLBP group made use of greater right hip flexion ($p=0.040$) and left hip flexion ($p=0.008$). These variations in the kinetic chain, indicate the different strategies of aligning the body to use the ground reaction forces at the start of the serve. Alterations in the

kinematic chain to accommodate for loss of force may lead to increased joint loading or overuse injuries (Martin *et al.*, 2014). This could explain why the LBP group made use of a rotatory mechanism (transverse plane) of force generation and transfer, whilst the NLBP group made more use of a vertical linear mechanism (sagittal plane) in order to generate and transfer forces.

Contributing to the kinematic findings was the greater muscle activation in the NLBP group for the right ES (p=0.000), as well as for the left ES (p=0.088) and for the right GM (p=0.083). These muscles are activated at a high threshold (Comerford and Mottram, 2012). This could suggest that the hip flexion and trunk kinematics at the PS phase are eccentrically controlled by the ES and GM musculature.

5.5.2 Preparation Phase: Ball Release (PR)

Interpretation of Kinematics and Muscle Activation of the NLBP Group

The point of ball release displays the trunk moving towards extension, rotation to the right and lateral flexion to the right (see Figure 5.2). For the NLBP group, the lateral flexion and rotation motions are close to neutral. The hips are flexing at the PR phase, with minimal hip abduction. The NLBP group displays internal rotation of the right hip and external rotation of the left hip. This position firstly, indicates the transfer of weight onto the right lower limb and secondly, display control mechanisms in order to stabilise the lower quarter while moving the upper quarter during the precision throwing task.

The anterior trunk muscles display a larger activation of the muscles on the left side, while the posterior trunk muscles show more activity on the right. Chow *et al.* (2003), reported

greater activation in the left EO combined with activation of the left RA and right EO, with minimal activation in the ES muscles. In the current study however, there is a small amount of muscle activity in the bilateral RA, EO, GM and the left ES, whilst the right ES display a greater activation. This could indicate that both anterior and posterior muscle groups are activating their global stabilisers and attempting to control through the range of movement, whilst the right ES is functioning as the global mobiliser.



Figure 5. 2 Preparation Phase: Ball Release (PR)

Discussion of Differences in Kinematics and Muscle Activation Between the Two Groups

From the results of the data analysis, it was found that at the point of ball release, the NLBP group remained in a position of hip flexion (right hip p=0.000 and left hip p=0.000), whilst the LBP group made use of more internal rotation of the trunk (p=0.006) and the left hip

(p=0.007). The NLBP group displayed more hip flexion on the right side, while the LBP group displayed more hip flexion on the left side. Compared to the NLBP group, the right hip of the LBP group was internally rotated to a greater degree. Compared to the LBP group, the left hip of the NLBP was externally rotated to a greater degree. A deduction that could be made is that the difference in hip flexion and rotation could be an indication as to which limb is carrying more weight (in this case, more than likely the left hip in the LBP group, with more weight bearing on the right hip in the NLBP group).

As in the PS phase, this position could be an indication of a stable base from which lumbo-pelvic motion can occur. Joint torques can generate and absorb mechanical energy whereas segment torques can transfer energy (Martin *et al.*, 2014). This may indicate that the NLBP group displays more effective lower-limb weight transfer through a linear torque system, while the LBP group makes greater use of force generation and transfer through the rotation of the trunk.

The NLBP group presented with a higher level of muscle activity of the right ES muscle (p=0.04) compared to the LBP group. The PR phase is a crucial point in the serve in that the positioning of the ball in the air is vital in determining effective ball contact (Kovacs and Ellenbecker, 2011c).

In the LBP group, it was found that the spine was still rotated towards the left, though rotation in the NLBP was closer to neutral. Interestingly, at this point, the NLBP group displayed greater muscle activation of the right EO muscle (p=0.001) as opposed to the LBP group. Furthermore, in the NLBP group, the muscle activation in the left and right EO proved to be

virtually equal (mean difference=0.49%), whilst in the LBP group results indicated a 1.77% greater activation level on the left side. It is possible that this may be a sign of inhibition and/or delayed recruitment for the purpose of pain adaptation (Hodges and Tucker, 2011).

5.5.3 Preparation Phase: Loading (PL)

Interpretation of Kinematics and Muscle Activation of the NLBP Group

The “lateral rear tilt” of the shoulder and pelvis in the loading phase is explained in the literature as a position where the right shoulder and hip are lower than the left shoulder and hip. This lateral rear tilt alignment facilitates the development of angular momentum through lateral flexion of the trunk which is a major factor in a high-velocity serve (Kovacs and Ellenbecker, 2011c). The lateral rear tilt can be seen in the results (see Figure 5.3). In the NLBP group, the trunk is still marginally flexed, continuing in lateral flexion to the right, and rotation motions to the right. Compared to the other phases, maximum hip flexion can be observed in the bilateral hips. The right hip is internally rotated and abducted. The left hip is externally rotated and adducted. This could be explained as a weight transfer that occurs during the loading phase, whereby the weight is shifted to the right, and supports the theory that the loading occurs from the legs up towards the trunk (Kovacs and Ellenbecker, 2011b). This process can contribute to the accumulation of potential energy.

There is greater muscle activity in the left RA, left EO, left ES and left GM. The role of the fast motor units are to rapidly accelerate movement and/or transfer the load during high load activity (Comerford and Mottram, 2012). The results at PL, could be an indication of eccentric muscle control during the loading phase of the lower quarter.

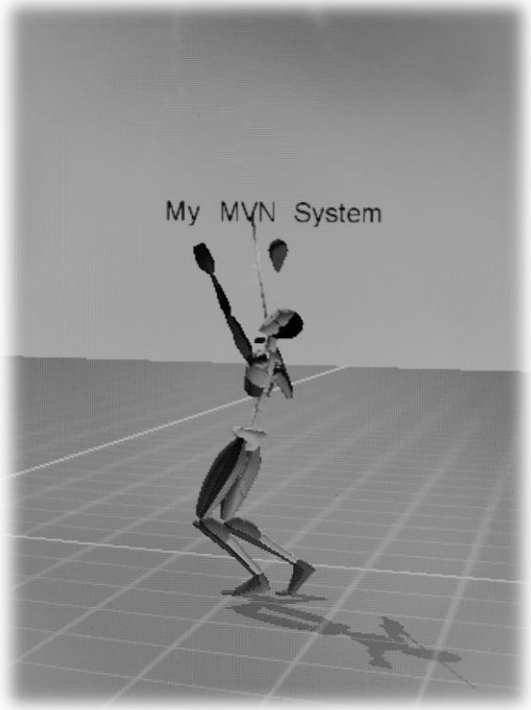


Figure 5. 3 Preparation Phase: Loading (PL)

Discussion of Differences in Kinematics and Muscle Activation Between the Two Groups

At the PL phase, the tennis player is starting to coil the trunk to the right. To achieve the optimal coiling or loading of the trunk, good flexibility and optimal core stability are required throughout the ROM (Chow, Shim and Lim, 2003; Kovacs and Ellenbecker, 2011a). The LBP group used less rotation to the right, and in fact, remained in rotation to the left. This could be an indication of muscular and/or myofascial restriction and lead to uncontrolled movement (Gibbons and Comerford, 2001a).

Research by Campbell *et al.* (2013), also reported a decrease in rotation towards the racquet arm from the loading to the cocking phase in the LBP group (Campbell *et al.*, 2013). Even though the kinematics for both groups does not display major differences, significant

differences can be seen in the abduction (p=0.007) of the right hip and the external rotation (p=0.000) motions of the left hip. This supports the findings in the previous phases regarding a difference in force generation strategies.

The results show that the NLBP group displays greater muscle activation of the right GM and right EO (p=0.055), and stabilising activation of the left ES and left RA (p=0.054) compared to the LBP group. In contrast to the NLBP group, the LBP group displays greater muscle activation of the right ES (p=0.003) and the right RA, whilst stabilising with the left GM and left EO. It is possible that the LBP group tried to generate force from the trunk, while the NLBP group used the combination of the hips and the trunk as the initiators of force. As explained by Hodges and Tucker (2011), these results can be regarded as modified muscle activation or a protective adaptation.

5.5.4 Preparation Phase: Cocking (PC)

Interpretation of Kinematics and Muscle Activation of the NLBP Group

In the literature, the cocking position is described as the spine extended, laterally flexed and rotated toward the racquet arm, with the racquet close to perpendicular to the ground (Kovacs and Ellenbecker, 2011b). This position can be observed in the data presented in Figure 5.4. However, at the cocking point, the spine has already started laterally flexing to the left. The trunk is extended, whilst laterally flexing to the left and rotated to the right in the NLBP group.

In Figure 5.4, the bilateral hips are still in a flexed position. The hips are adducting and externally rotating. This position could be explained in terms of the fact that the hips and

pelvis are “coiled up” in the process of force production. The cocking phase is the last point in the preparation process. It can be regarded as the milliseconds of complete change in direction. In the present study, both groups display high levels of muscle activation in the left musculature (especially in the left EO). It has been shown that the left RA, left EO and left internal oblique was activated at the cocking point (Chow, Shim and Lim, 2003). This is an indication of eccentric muscle activation in an attempt to control the end of the cocking phase.



Figure 5. 4 Preparation Phase: Cocking (PC)

Discussion of Differences in Kinematics and Muscle Activation Between the Two Groups

An effective cocking position is a result of an efficient loading phase (Kovacs and Ellenbecker, 2011c). When analysing the loading phase differences are seen in the anterior

and posterior trunk muscle activity between the two groups. The significant differences found between the two groups in the cocking phase can be observed in the right hip rotation ($p=0.017$), right hip flexion ($p=0.021$) and left hip rotation ($p=0.047$). In the NLBP group, the bilateral hips are flexed. In contrast, in the LBP group, the right hip is close to neutral and the left hip is flexed. The NLBP group displays external rotation in the hips, whilst the LBP group displays internal rotation in the hips.

The explained biomechanics of the NLBP group display a stable, close-to-equal weight-bearing base, with the hips opened up. Compressive forces are required for the storage of potential energy (Lim, Chow and Chae, 2012). The NLBP group make use of hip flexion in order to compress and store potential energy. The LBP group is unable to reach the same position in bilateral hips. It can be explained as a difference in the approach to and the production of the compressive forces required at the PC phase between the two groups. This could support the results explained in the previous phases, namely that the NLBP group makes use of vertical linear mechanisms, whilst the LBP group makes use of rotatory mechanisms for force generation and transfer.

The muscle activation ($p=0.013$) in the left RA of the NLBP group is greater than that of the LBP group. On the other hand, the muscle activation ($p=0.078$) in the right RA of the LBP group is greater than that in the NLBP group. In this case, the function of the left RA and left EO can be regarded as eccentric stabilisation, controlling the motion before a change in direction. This might indicate a delay in muscle activation, where the LBP group shows slower activation of the left RA and a slower relaxation of the right RA, or the finding can indicate a pain inhibition mechanism in the LBP group. The results throughout the

preparation phase, display the importance of the eccentric muscle control of the global stabilisers.

In the NLBP group, the trunk is rotated to the right and greater use is made of the trunk extension. In contrast, the LBP group is rotated to the left, although close to neutral, and uses less trunk extension. Video footage does in fact indicate that the spine of the LBP group rotates to the right. Therefore, the results describe that only the lumbar trunk segment is rotated away from the racquet arm.

The results of this study can be associated with a study done by Campbell *et al.*, (2013). Here, the researcher looked at the kinematics, kinetics and forces developed in the lumbar region during the tennis serve. They reported that the LBP group uses a marginally greater right lateral flexion and an angular velocity rotation in the drive phase than the NLBP group. The pain group also displays peak lateral flexion forces approximately four times their body weight that are around 50% greater than those of the no pain group. These researchers concluded that the extension and lateral flexion of the lumbar spine, coupled with the increased lateral flexion forces, stiffen the spinal segments to limit the extent to which players can rotate (Campbell *et al.*, 2013).

The results of the PC phase could support the theory of motor control dysfunction (Gibbons and Comerford, 2001a). The restriction in rotation and the delayed muscle activation could be the cause of the significant differences observed between the two groups in the PL and PC phases. Future studies could look at a combination of force and muscle activation in tennis players with and without lower back pain.

5.5.5 Acceleration Phase: Ball Contact (AC1)

Interpretation of Kinematics and Muscle Activation of the NLBP Group

During the acceleration phase, the potential energy that was generated in the lower quarter is now converted into kinetic energy for force production. The potential energy is converted into kinetic energy in the acceleration phase through the legs and back and drives the body forward towards the net (see Figure 5.5). This occurs while the lower quarter rotates towards the non-dominant side (Abrams *et al.*, 2011). During the transition between the cocking phase and the acceleration phase, the lumbar region needs to rapidly ‘‘recoil’’ (or flex with simultaneous rotation and lateral flexion away from the racquet arm) (Campbell *et al.*, 2013).

Customarily, the tennis player will be airborne at this point in the serve. As opposed to the right side, both groups present with a greater muscle activation of the left RA and left EO. This is comparable to the findings of Chow *et al.* (2003). The left anterior trunk muscles play a role as a global mobiliser to accelerate the movement of the spine toward the left. The NLBP group displays muscle activation in the bilateral ES and GM muscles that are close to equal and that could suggest to the global stabilising function in order to control through movement.

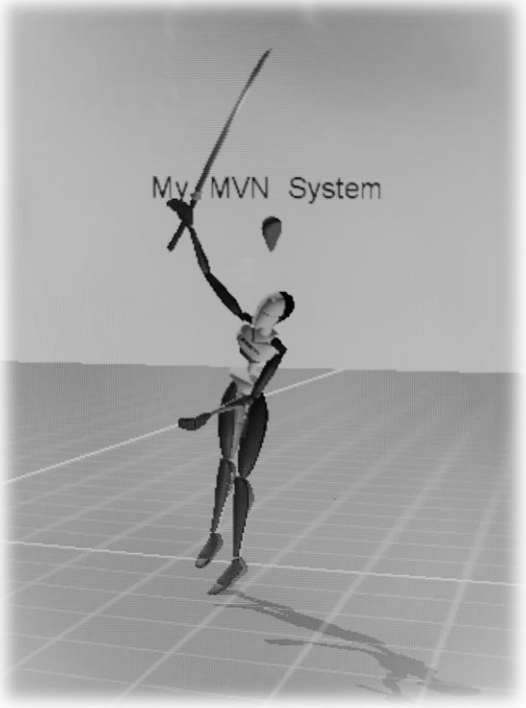


Figure 5. 5 Acceleration Phase: Ball Contact (AC1)

Discussion of Differences in Kinematics and Muscle Activation Between the Two Groups

Significant differences between the two groups can be seen in the flexion motions of the right hip (p=0.005), the internal rotation motions of the left hip (p=0.010) and the flexion motions of the left hip (p=0.045). The NLBP group retains a greater degree of hip flexion during the acceleration phase. In the NLBP group, the right hip is in external rotation, whilst in the LBP group the right hip is in internal hip rotation, however, this is not significant. In both groups, the left hip is internally rotated. For the NLBP group, the internal rotation of the left hip is close to neutral, whilst in the LBP group, it is not.

The differences in the flexion and rotation of the hips could partly contribute to the differences in force generation and in the transfer mechanisms. Passive elasticity (Lim,

Chow and Chae, 2012) and neuromuscular control (Comerford and Mottram, 2012), are two factors that could influence the flexion and rotation motion around the hip joint. It is possible that the NLBP group is able to retain a certain amount of potential energy to use for shock absorption during the landing phase. This potential energy can be stored through neuromuscular control mechanisms.

Interestingly, the NLBP group was found to have a close-to-equal muscle activation in the bilateral ES and GM, whilst the LBP group displayed a greater activation in the left ES compared to the right ES, right GM and left GM. The left ES of the LBP group was also found to be greater when compared to the NLBP group ($p=0.051$). These results display differences in global stability between the two groups. Furthermore, compared to the LBP group, the NLBP group displayed greater activation in the right EO ($p=0.051$). A possible explanation would be that the right EO works as a stabiliser in order to eccentrically control the spine during acceleration.

5.5.6 Acceleration Phase: Point of Stretch (AC2)

Interpretation of Kinematics and Muscle Activation of the NLBP Group

As explained in the methodology, the phase of maximum shoulder abduction is used to examine the point of stretch in the biomechanical chain. The kinematics at the AC2 phase are similar to the AC1 phase, as these two points are very close together. The tennis player is still airborne at this point and presumably, the biomechanics of the tennis player are preparing for the landing and the finishing point of the tennis serve (see Figure 5.6).

A comparison of the muscle activation at phases AC2 and AC1 shows that the muscle activity of the anterior trunk muscles has decreased, whilst that of the posterior trunk has increased, especially in the case of the ES. For the NLBP group, the left RA and left EO has a greater muscle activation compared to the right side – forward flexing and moving the trunk toward the left. On the other hand, the right ES and right GM show greater muscle activation than the left side – thus eccentrically controlling the motion in the trunk.

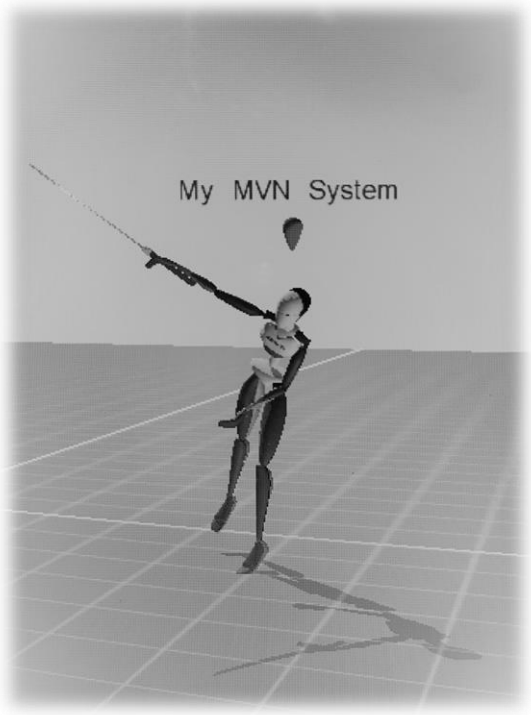


Figure 5. 6 Acceleration Phase: Point of Stretch (AC2)

Discussion of Differences in Kinematics and Muscle Activation Between the Two Groups

The NLBP group displayed significantly more hip flexion compared to the LBP group (left p=0.009 and right p=0.009). The results pertaining to hip flexion indicate that compared to the NLBP group, the LBP group was in a lengthened position. It is possible, on the other

hand, that the tennis players in the NLBP group were able to store potential energy for the landing and deceleration phase through hip flexion.

The NLBP group displayed greater force coupled activation during the acceleration phase with greater muscle activation in the right EO (p=0.021) and left RA (p=0.077) muscles. These force couples could function as global stabilising and mobilising units. The results indicate that possibly the NLBP group makes better use of force couples to stabilise the spine whilst accelerating to the left.

Chow *et al.* (2003), reports a high activation level of the left internal oblique muscle at the end of the preparation phase and during the acceleration phase. Although the internal oblique muscles were not tested in this study, this could suggest a further force couple between the left internal oblique, the bilateral RA and right EO anterior trunk musculature.

Players with lower back pain have been shown to experience a reduction in muscle endurance, especially in the abdominal muscles, in the side bridge position (Correia *et al.*, 2016). The side bridge position illustrates the stabilising function of the EO muscles. In the present study, the LBP group displayed less muscle activation in the right EO muscle (p=0.021), and greater activation in the left ES muscle (p=0.000). It is possible that during the AC2 phase, the LBP group had a similar reduction in muscle endurance and further, was employing a mal-adaptive mechanism to control the segment.

The NLBP group displayed a small range of muscle activity in all of the musculature. In contrast, the LBP group displayed a greater range of muscle activation. In terms of changes in strength and flexibility, muscle imbalance, can alter the joint biomechanics and lead to a reduced maximal force output (Kibler and Safran, 2005; Hjelm, Werner and Renstrom, 2012). In turn, as explained by Hodges and Tucker (2011), all of the possible adaptations mentioned above have short-term benefits but could have potentially long-term consequences.

5.5.7 Deceleration Phase: Final (DF)

Interpretation of Kinematics and Muscle Activation of the NLBP Group

The trunk motion at the termination ("finish") of the deceleration phase is described in literature as including forward flexion, lateral flexion and rotation to the left (away from the racquet arm) (Kovacs and Ellenbecker, 2011b). The player also needs to rapidly recover from the service motion and be ready for the return stroke (see Figure 5.7).

The NLBP group displayed trunk flexion, lateral flexion to the left and rotation to the left. The bilateral hips were in flexion and adducted during the deceleration phase (DF). In both groups, the right hip was more flexed than the left hip and the left hip was rotated to a greater extent than the right hip. The results display the mechanical energy flow through the kinetic chain for the tennis serve (Martin *et al.*, 2014).

The RA and EO muscles both indicated a limited level of muscle activity. The RA and EO muscles could be activated in order to stabilise and control through ROM. Furthermore, the right ES muscle was shown to eccentrically control the deceleration of the movement.

Muscle activation in the left GM was greater than that in the right GM. The harmonious co-activation of global stabilisers and mobilisers can be seen during the deceleration phase.



Figure 5. 7 Deceleration Phase: Final (DF)

Discussion of Differences in Kinematics and Muscle Activation Between the Two Groups

The deceleration force between the trunk and the arm could be 300 N or higher (Kovacs and Ellenbecker, 2011c). Uncontrolled movement of the LBP group could be seen in both the trunk and the hip motions. The LBP group displayed more lateral flexion ($p=0.009$) of the trunk, and rotation to the left ($p=0.046$). A trend for a greater level of rotation in the left lumbar region (away from the racquet arm) during the acceleration to deceleration phases was also observed in a study done by Campbell *et al.* (2013). In contrast, the NLBP group displayed greater flexion in the trunk ($p=0.002$) than that displayed in the LBP group. This could be attributed to the different deceleration strategies that were available at the time and

that the groups could use. This study proposes, the NLBP group made use a vertical linear mechanism, whilst the LBP group made use of a rotatory mechanism.

Furthermore, the LBP group relied on greater levels of bilateral hip flexion (left p=0.012 and right p=0.002), as well as, adduction (p=0.056), and internal rotation (p=0.004) in the left hip. The NLBP group revealed greater adduction in the right hip than in the left hip. On the other hand, the LBP group displayed virtually the same level of adduction in both hips. It is possible that the LBP group displayed less control at this point and therefore had a greater range of movement in the bilateral hips.

During the landing phase, the body needs to slow down the motion by eccentrically controlling the muscles in order to effectively absorb the forces. To stabilise the trunk during this unbalanced posture, the right ES becomes more active during the deceleration phase (Chow, Shim and Lim, 2003). In the present study, the LBP group displayed greater muscle activation in the left ES (p=0.001), right ES (p=0.021), left EO (p=0.000), left RA (p=0.036) and right RA (p=0.069). As stated in the literature review, the RA muscles functions mainly as a global mobiliser. It is possible that combined muscle activation is an attempt at compensating in order to fixate and attempt to stabilise the uncontrolled movement, and/or it could indicate delayed recruitment of the global stabilisers and mobilisers. The fixation is usually attributed to a dysfunction of the local and global stabilisers (Comerford and Mottram, 2012).

A comparison of the left and right sides in this research study showed that the muscle activation in the NLBP group was greater, in the right EO (utilising eccentric control), whilst,

in the LBP group was greater in the left EO muscle (utilising concentric control). This could be a sign of delayed recruitment and/or poor timing in muscle activation in the case of the LBP group.

In summary, in contrast, to the NLBP group, which made use of a vertical linear approach for generating and transferring force at the end of a serve, the LBP group proved to be successful in propelling the ball forward over the net at the end of a serve as a result of differences in the kinematics and endeavoured adaptations that came into play. However, these adaptations seem to have caused a rotatory mechanism to generate and transfer forces. Because the rotatory mechanism causes changes in muscle activation, it may lead to microtrauma on account of the uncontrolled movement.

5.5.8 Timing of Maximum Muscle Activation during the Serve

In the LBP group, the difference in greatest muscle activation displays an ineffectiveness in timing, pain inhibition and/or mal-adaptation to recruit motor units in order to gain stability.

The findings suggest a difference in timing of the trunk musculature (RA and EO) between the two groups. This was seen between the PC and AC phases and AC to the DF phase. As previously stated, the RA muscle is a global mobiliser, while the EO muscle is a global stabiliser. Chow *et al*. (2003) reported a high degree of co-contraction during the tennis serve, especially from the end of the preparation phase, through the acceleration phase, to the end of the deceleration phase. It is possible that a delay could occur in the reflex response of the trunk muscles. This is described in the literature as pain inhibition of the neuro-muscular feedback pathway and/or motor units (Comerford and Mottram, 2012).

As regards to the left ES muscle, the timing for greater muscle activation in the NLBP group is from the PL phase to the PC phase, whereas it is from the PC to the AC phase for the LBP group. These findings also suggest delayed activation or inhibition due to the pain response. Hides *et al.* (1996) reported that multifidus muscle recovery is not spontaneous on remission of painful symptoms. The mentioned pain inhibition may lead to uncontrolled movement that results in or is exacerbated by a lack of recruitment in motor units.

In other words, to ensure stability of the spine in order to produce force and to prevent injury, the trunk muscles must have sufficient strength and endurance, and be able to initiate certain recruitment patterns (Faries and Greenwood, 2007). The kinematic response of the trunk to ensure a particular level of stability, as in this study, is determined by the mechanical stability level of the spine and the reflex response of the trunk muscles prior to force being applied to the body (Faries and Greenwood, 2007). This could be explained as the effectiveness of combinations of motor control in the anterior and posterior trunk musculature, with the global mobilising and global stabilising functions of muscles co-contracting to produce control through range of movement.

5.5.9 Relationship between Variables to Determine Lower Back Pain Status

From the correlation data, the logistic regression results indicate that bilateral hip motion (especially the non-dominant limb) and anterior trunk muscle activation could be determining factors in deciding whether a player has LBP or not. Emphasis will be placed on three possible concepts – key points, which are presented in Table 5.1.

Table 5. 1 Probability Factors for Classification into the NLBP (n=21) and LBP (n=12) Groups

Phase	Action	Area	OR	Probability	Group
Motivation for Key Point 1					
PS	↑ degree flexion	Left hip	0.750	25%	NLBP
PR	↑ degree flexion	Right hip	0.620	38%	NLBP
PR	↓ degree external rotation	Left hip	1.406	41%	LBP
PL	↑ degree external rotation	Left hip	0.866	13%	NLBP
Motivation for Key Point 2					
DF	↓ degree adduction	Left hip	0.533	47%	NLBP
DF	↑ degree internal rotation	Left hip	1.252	25%	LBP
DF	↑ degree flexion	Left hip	1.269	27%	LBP
Motivation for Key Point 3					
PL	↑ percentage muscle activity	Left RA	0.645	36%	NLBP
PL	↓ percentage muscle activity	Right EO	1.101	10%	LBP
DF	↑ percentage muscle activity	Right RA	1.537	54%	LBP

NLBP – participants without lower back pain; LBP – participants with lower back pain. PS – preparation phase: start of serve; PR – preparation phase: ball release point of serve; PL – preparation phase: loading point of serve; DF – deceleration phase: finish point

Key point 1 as a guideline to identifying LBP – Preparation Phase

In the left hip, a tennis player with LBP displays little to no external rotation between the ball release and the loading phases (see Table 5.1). During the preparation phase, external rotational motion occurs in combination with hip flexion motion, with the left hip flexion angles increasing from 30° to 84° (PR to PL). An increase in flexion and in the external rotational angles of the hips opens the pelvis up to broaden the base of support for the lower quarter. Attention should, therefore, be placed on positioning and broadening a stable base of support through the utilisation of external rotation, whilst implementing effective hip flexion motions during the preparation phase.

Key point 2 as a guideline to identifying LBP – Deceleration Phase

At the finish point of the serve, one needs to be aware of greater adduction (NLBP 0.15°; LBP 1°), internal rotation (NLBP 15°; LBP 24°) and larger flexion angles (NLBP 50°; LBP 57°) in the left hip (Table 5.1). If these values are not within the acceptable parameters, as described, the ensuing condition could be described as poor control of range of motion during deceleration. The player with LBP struggles to effectively control the final moments in the tennis serve, which causes an unstable base of support. It is likely that the player would be unable to effectively transfer forces in the lower quarter. Coaches should, therefore, monitor and heed the combination of bilateral hip adduction, internal rotation and flexion angles (closing of the pelvis) at the finish of the serve.

Key point 3 as a guideline to identifying LBP – Anterior Trunk Muscles

At the loading phase, the greater activation of the left RA (NLBP 8%; LBP 5%) and right EO muscles (NLBP 10%; LBP 6%) is a determining factor for the NLBP group. The eccentric control of the left RA and the concentric stabilisation of the right EO constitute an important force couple during the loading point of the preparation phase. Furthermore, at the end of the serve, the LBP group displayed greater muscle activation in the right RA (NLBP 1.6%; LBP 2%). The analysis of muscle activation brought to light that the LBP group is more likely to display higher muscle activation levels of the left RA from the AC to the DF phase ($p=0.003$). On the other hand, the NLBP group displayed higher muscle activation levels for this same muscle ($p=0.0030$) from the PC to the AC phase. A possible explanation could be that the LBP group presented with a delayed onset of muscle activation in the anterior trunk muscles. Through these results, emphasis can now confidently be placed on an assessment of the anterior trunk muscles in terms of concentric and eccentric motor control (Table 5.1).

The results issuing from the logistic regression analysis further substantiate the interpretation of the results in terms of the kinematics and motion analysis of the tennis serve that were discussed previously. Chosen risk factors, identified and discussed in the literature review – Chapter 2, were analysed in this study. The risk factors that displayed a significant difference between the two groups was used in the logistic regression model. The probability findings can be used by clinicians and coaches as key points or guidelines for identifying and coaching players with a greater likelihood of developing LBP.

These three key points need to be considered as helpful in the treatment and training of adolescent tennis players. Video footage is freely available from smartphones, as are slow-motion settings from most smartphone brands. The researcher suggests the use of regular video analyses of the tennis serve in order to analyse motion during the preparation and deceleration phases. Clinicians also need to consistently evaluate muscle strength and motor control in the anterior trunk muscles (RA and EO). The three key points should serve as the basis for further research endeavours to practically evaluate whether this could be a preventative measurement tool that could mitigate the risk of LBP.

5.6 Implications of the Discussion

All variables were categorically discussed in the discussion chapter. The main findings showed a difference in motion and muscle activation between the two groups. It remains unknown whether the pain adaptation and compensatory mechanism arose as a result of the change in kinematics (restriction or hypermobility) first or of muscle activation (motor unit

recruitment). The “chicken *versus* egg” scenario – or causality – remains a mystery owing to the cross-sectional design used in this study.

However, the fact remains that unsatisfactory kinematics and muscle activation strategies can be effectively rehabilitated (Gibbons and Comerford, 2001a, 2001b; Kovacs, 2009; Perry *et al.*, 2009; Roetert, Ellenbecker and Reid, 2009; Hodges and Tucker, 2011; Kovacs and Ellenbecker, 2011a; Correia *et al.*, 2016). Faries and Greenwood (2007) report a concern that too much strength or force from core musculature can cause greater instability if it is not directed correctly. Muscle endurance has been reported as the more important training variable when it comes to the core musculature and motor control (Chow, Shim and Lim, 2003; Faries and Greenwood, 2007; Correia *et al.*, 2016).

Competitive players should focus in their training on physical aspects such as strength, speed, power, flexibility, local muscle endurance and muscular balance in order to prevent injury (Baiget *et al.*, 2016). Kovacs (2009), also reports the importance of lateral training. Imperative aspects need to be considered when looking at the rehabilitation of tennis players with lower back pain: firstly, pain can increase, decrease or not change muscle activity (Hodges and Tucker, 2011), and secondly, the recruitment of the stability function of a muscle requires cognitive and motor coordination strategies (Gibbons and Comerford, 2001b). Finally, a balance between the strength and stability function of the core musculature needs to be reached (Faries and Greenwood, 2007).

5.7 Conclusion of Discussion

This chapter discussed valuable intrinsic and extrinsic risk factors contributing to injury in adolescent tennis players. Intrinsic and extrinsic risk factors were discussed in the literature review before the chosen variable were used in the study. Emphasis was placed on kinematics and muscle activation during the serve. The organisational chart featured in the introductory chapter displays a summary of the chapters for this dissertation. Digging down into the rabbit hole of discovery, we attempted to clarify and discuss a small piece of a bigger picture. Three key points that could aid in the identification of risk factors for LBP were then discussed.

The analysis of the kinematics and muscle activation during the tennis serve ascertained the following:

(1) The LBP group displays different muscle activation and kinematic mechanisms in the hips and trunk. The aim of the tennis player remains to move the body through space by using force mechanisms. As a result, the LBP group uses a rotatory mechanism, whilst the NLBP group uses a vertical linear mechanism more to accommodate these conditions;

(2) The recruitment of motor units is slower in the LBP group;

(3) The movement patterns of the trunk and hips in the LBP group are mal-adaptive in terms of shock absorption.

We can conclude that the LBP group makes use of compensatory mechanisms in order to adapt to pain and/or restrictions and therefore displays a lack of motor control.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Conclusions Based on Findings

This study aimed to examine the activation and kinematics of the lower quarter muscles during the tennis serve. It further aimed to analyse other variables that could have an effect on the tennis player's lower back pain status. The conclusions of this study are presented in alignment with the objectives.

The objectives were as follows:

1. **Compare the muscle activation of the lower quarter muscles during the different phases of the tennis serve in adolescent tennis players with and without lower back pain.**

   Generally, as opposed to the LBP group, the NLBP group had greater muscle activation in the RA muscles during the loading, cocking and acceleration phases. The NLBP group displayed greater muscle activation of the EO muscles from the ball release phase to the acceleration phase. The ES and GM were more activated during the preparation phase for the NLBP group. However, the ES was more active in the LBP group in most phases (PL to DF). During the end phase of the serve (DF), the LBP group experienced greater activation in the anterior and posterior trunk musculature. Further analysis of the results indicated that the NLBP group displayed faster recruitment in maximum muscle activation than the LBP group.

2. **Compare the joint angles of the lower quarter (kinematics) during the different phases of the tennis serve in adolescent tennis players with and without lower back pain.**

   An evaluation of the tennis serve shows that the two groups displayed different preparation and execution strategies in terms of the kinematics and weight transfer needed to move between the respective phases. The NLBP group made use of a greater angle of hip flexion during the serve. In contrast, the LBP group made use of greater angles of rotation and lateral flexion during the serve.

3. **Compare the demographic history and behaviour, active range of motion (ROM) and dynamic lower limb balance in adolescent tennis players with and without lower back pain.**

   In this respect, it is important to look at the demographics and the past history of the tennis player. Differences between the two groups showed a few aspects that can be kept in mind during evaluation and training. The LBP group consisted of more left lower-limb dominant tennis players and therefore required an individualised approach to training and strengthening programmes. The distribution of hours spent playing tennis showed significant differences between the two groups. The LBP group spent two hours longer playing tennis on a hard-court surface. Furthermore, as opposed to the NLBP group, the LBP group spent two hours less playing other types of sport.

   A reduction in the active ROM could be an effective tool to measure in establishing the presence of lower back pain. Specifically, a restriction in lateral flexion (toward the racquet arm) could be an indication of lower back pain status. Furthermore, the

contrast in the active ROM and the kinematics of the tennis serve suggests that a motor control approach would be more beneficial than a flexibility approach when rehabilitating the restrictions associated with the active ROM.

In this study, the SEBT directions displayed a greater reach in the LBP group in the anterior, anteromedial, anterolateral, posterolateral and posterior directions. This may suggest that the LBP group uses better dynamic strategies for lower limb balance. It is possible that the LBP group makes use of fixation compensatory mechanisms which results in better dynamic balance strategies. The SEBT may therefore not be an effective tool for measuring LBP status in adolescent tennis players.

4. **Determine the relationship between the active ROM, dynamic lower limb balance, kinematics, and muscle activation during the serve in adolescent tennis players with and without lower back pain.**

   The logistic regression analysis results displayed three key points (guidelines) that could assist in the identification of risk factors for LBP during the tennis serve:

   - Firstly, a smaller angle of hip flexion and external rotation during the preparation phase;
   - Secondly, a greater degree of adduction, internal rotation and flexion of the hip during the deceleration phase. [These two kinematic key points emphasise the importance of force transfer over a stable base of support.];
   - Thirdly, the importance of correct muscle activation (concentric and eccentric) of the anterior trunk, and control throughout movement during the loading and

deceleration phases. [This muscle-activity key point emphasises the importance of muscle strength and the global stability functional testing.]

One of the major strengths of this study is that the identification of variables that have an effect on lower back pain status can aid in the prevention and rehabilitation programmes. The differences in hip and trunk kinematics between the two groups allude to different force generation and transfer strategies. This has been explained as a vertical linear mechanism (in the NLBP group) *versus* a rotatory mechanism (in the LBP group) for force generation and transfer. Furthermore, it is possible that the NLBP group retains a certain amount of potential energy through the serve to use for shock absorption during each phase. Consequently, these mechanisms have an effect on the compressive forces during the serve. Furthermore, alteration in the force mechanisms may cause microtrauma in the lower back structures, or in the worst-case scenario, spondylolisthesis.

For this reason, the clinical recommendations of this study are to identify trunk rotation and hip flexion kinematics, as well as the correct recruitment of the ES, GM, RA and EO muscles. These findings can be used in motor-control re-training and in other rehabilitation programmes. These measures could impact on the high incidence of lower back pain and chronic pain in the future.

6.2 Practical Implications

Based on this reasoning, a few practical implications could be made from the results of this study. However, it is important to highlight the fact that the findings of this study should be regarded as guidelines and not rules.

- If a tennis player spends more than six hours a week practising on a hard-court surface, it might be beneficial to recommend the benefits of participation in other types of sport. For example, the tennis player that plays tennis for eight hours a week could participate in other types of sport for two to three hours a week and reduce the number of hours playing tennis. Although this might be a difficult piece of advice for tennis players to accept, the rewards that they may reap in the long term will outweigh the possible frustrations. Hours of playing tennis and participating in other sports should be monitored in adolescent tennis players, especially if they suffer from lower back pain.

- Active ROM in standing, as well as in the kinematics of the trunk and hip motions during the tennis serve, should be assessed regularly in adolescent tennis players as a preventative and rehabilitative strategy.

- Motor control strategies of hip flexion and lumbar rotation should form part of regular training programmes.

- Concentric and eccentric recruitment exercises of the anterior and posterior trunk musculature (especially for the RA and EO muscles) should be encouraged in adolescent tennis players. These exercises should focus on the global stabilisation function of the muscle groups during functional tasks.

- Trainers, clinicians and coaches could apply the findings of this study to their current training and injury-prevention programmes.

6.3 Limitations of this study

The interpretation of these findings requires that some of the limitations that were present should be considered. In order to eliminate bias, the sample size in this study was

unbalanced, and was determined without any knowledge of back pain status in the participants. The participants in this research project could therefore be regarded as constituting a true sample of the North Gauteng Tennis Club. However, the sample is still of limited size. This may have prevented us from drawing conclusive statements pertaining to other tennis clubs and larger sample sizes. Therefore, the type of participants that participated in this study did not permit any generalisations as to the findings beyond those associated with an elite group of adolescent tennis players.

Even though the results might have given us more clarity on global stabilisation and force couples, it was decided by the researcher not to incorporate the internal oblique muscles into the current study. sEMG rather than fEMG was established as the electrode of choice for this active adolescent population. Because the internal oblique muscles lie deep below the RA and EO muscles, inaccurate data could have been captured by the sEMG electrodes.

All technology has limitations and the reliability of the IMU system and the sEMG system has not been thoroughly documented. These results can be regarded as guidelines and require further study until the reliability of these measurement systems are fully researched. Furthermore, the data collection phase did not take place on the same day. This could have introduced bias or could have contaminated the findings.

6.4 Recommendations for Future Studies

The prevention and treatment of injury have been widely researched. This study has shed some light on the risk factors for adolescent tennis players. The researcher wishes to

make a few recommendations that could be valuable guidelines to use in future research into adolescent tennis players.

- In future studies, it might be beneficial to look at the individual assessment of the internal rotational deficit of the hip, or HIRD, in conjunction with muscle activation. As discussed, this could point to possible muscle imbalances around the hip joint in tennis players.
- The SEBT as a test of dynamic lower limb balance needs to be further investigated in terms of adolescent tennis players specifically. Munro and Herrington (2010) report that excursion distances stabilise after four trials and it might be beneficial to conduct seven trials to attain reliable results. It might be beneficial in the case of adolescents to carry out practice trials a week before the commencement of the test to eliminate the bias of “learning effects”.
- The difference in active ROM and the kinematics of the lumbar spine could also be a topic for further investigation. This may give more insight into motor control in the lumbar region of tennis players with and without lower back pain.
- As suggested in a study by Campbell *et al.* (2013), it is possible that the lack of muscle activity in the LBP group during the preparation phase could contribute to the strong forces found in the trunk. Future studies could look at a combination of forces and muscle activation in tennis players with and without lower back pain.
- The use of analyses of smartphone videos of the serve in adolescent tennis players could be an easy, cost-effective tool to identify possible risk factors for the preparation and deceleration phases. Further research is necessary to validate the effectiveness of such a tool in prevention strategies.

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APPENDICES

APPENDIX I: Data Labels for the Self-report Questionnaire:

Consent:

- I agree to participate in the study as described to me in the information sheet and I'm aware that I have the right to withdraw at any time without suffering any repercussions. (choice=Yes/No)
- I am aware that I will not be exposed to any additional risks other than those usually experienced during tennis. (choice=Yes/No)
- I understand that there are no monetary rewards for my participation; that participation is voluntary and that I am not in any way obliged to take part. (choice=Yes/No)

Inclusion/Exclusion Criteria:

- Do you have any injuries at the moment that prevent you from playing tennis? / Het jy enige beserings op die oomblik wat maak dat jy nie tennis kan speel nie? (choice=Yes/No)
- Where is the injury? / Waar is die besering? (choice/keuse=Upper Body/Bo-liggaam)
- Where is the injury? / Waar is die besering? (choice/keuse =Lower Body/Onder-liggaam)
- Where is the injury? / Waar is die besering? (choice/keuse =Trunk/Middel-lyf of rug)
- Where is the injury? / Waar is die besering? (choice/keuse =Other/Ander) Please specify / Spesifiseer asseblief
- Have you been diagnosed with any condition? / Is jy al ooit gediagnoseer met enige van die volgende mediese toestande? (choice/keuse =Metabolic/Metabolies)
- Have you been diagnosed with any condition? / Is jy al ooit gediagnoseer met enige van die volgende mediese toestande? (choice/keuse =Genetic/Geneties)
- Have you been diagnosed with any condition? / Is jy al ooit gediagnoseer met enige van die volgende mediese toestande? (choice/keuse =Tumour/Gewas)
- Have you been diagnosed with any condition? / Is jy al ooit gediagnoseer met enige van die volgende mediese toestande? (choice/keuse =Other/Ander) Please explain. / Verduidelik asseblief.
- Have you been diagnosed with any condition? / Is jy al ooit gediagnoseer met enige van die volgende mediese toestande? (choice/keuse =None/Geen)

- Have you had any operations on your back? / Het jy al enige rugoperasies ondergaan? (choice/keuse =Yes/No) Please explain. / Verduidelik asseblief.
- Have you been diagnosed with a back condition by any doctor? / Is jy al met ‘n rugprobleem deur enige dokter gediagnoseer? (choice/keuse =Sheuermans)
- Have you been diagnosed with a back condition by any doctor? / Is jy al met n rugprobleem deur enige dokter gediagnoseer? (choice/keuse =Ankylosing Spondylitis)
- Have you been diagnosed with a back condition by a doctor? / Is jy al met n rugprobleem deur enige dokter gediagnoseer? (choice/keuse =Spondylolysis)
- Have you been diagnosed with a back condition by any doctor? / Is jy al met n rugprobleem deur enige dokter gediagnoseer? (choice/keuse =Spondylolisthesis)
- Have you been diagnosed with a back condition by any doctor? / Is jy al met n rugprobleem deur enige dokter gediagnoseer? (choice/keuse =Other/Ander) Please explain. / Verduidelik asseblief.
- Have you been diagnosed with a back condition by any doctor? / Is jy al met n rugprobleem deur enige dokter gediagnoseer? (choice/keuse =None/Geen)

Questionnaire:

- Allocated number / Aangewysde nommer
- Age / Ouderdom:
- Gender / Geslag:
- Weight / Gewig (kg):
- Height / Lengte (cm):
- Arm Dominance/Arm Dominansie: (choice/keuse=right/regterarm; left/linkerarm; ambidextrous/dubbelhandig; not sure/nie seker nie)
- Leg Limb Dominance / Beendominansie: (choice/keuse=right/regterbeen, left/linkerbeen, ambidextrous/dubblebenig , not sure/nie seker nie)
- How many years have you played tennis? / Hoeveel jaar speel jy al tennis?
- How old were you when you started playing tennis? / Hoe oud was jy toe jy tennis begin speel het?
- Do you play singles, doubles or both? / Speel jy enkelspel, dubbelspel of albei? (choice/keuse=singles/enkelspel; doubles/dubbelspel; both/beide)
- What type of serve do you use? / Van watter tipe afslaan maak jy gebruik? (choice/keuse=Topspin)

- What type of serve do you use? / Van watter tipe afslaan maak jy gebruik? (choice/keuse=Flat/Plat)
- What type of serve do you use? / Van watter tipe afslaan maak jy gebruik? (choice/keuse=Slice)
- What type of serve do you use? / Van watter tipe afslaan maak jy gebruik? (choice/keuse=not sure / nie seker nie)
- How often do you use a topspin serve in a game? / Hoeveel keer slaan jy so per spel af(topspin)?
- How often do you use a flat serve in a game? / Hoeveel keer slaan jy so per spel af(flat/plat)?
- How often do you use a slice serve in a game? / Hoeveel keer slaan jy so per spel af (slice)?
- What type of court surfaces do you play on? / Op watter tipe baanoppervlakte speel jy? (choice/keuse=hard court / harde baan)
- What type of court surfaces do you play on? / Op watter tipe baanoppervlakte speel jy? (choice/keuse =Grass / Gras)
- What type of court surfaces do you play on? / Op watter tipe baanoppervlakte speel jy? (choice/keuse =Clay / Klei)
- What type of court surfaces do you play on? / Op watter tipe baanoppervlakte speel jy? (choice/keuse =Not sure / Nie seker nie)
- How many hours a week do you play on a hard-court surface? / Hoeveel uur per week speel jy op ‘n harde baan?
- How many hours a week do you play on grass? / Hoeveel uur per week speel jy op gras?
- How many hours a week do you play on clay? / Hoeveel uur per week speel jy op klei?
- How many hours do you practise tennis per week? / Hoeveel uur per week oefen jy tennis?
- How many hours per week do you play singles matches/competitions? / Hoeveel uur per week speel jy in wedstryde of enkelspeltoernooie?
- How many hours per week do you play doubles matches/competitions? / Hoeveel uur per week speel jy in wedstryde of dubbelspeltoernooie?
- Do you participate in other sports? / Neem jy aan ander sportsoorte deel? (choice/keuse=Yes/Ja/No/Nee)
- Which other sport(s) do you play? / In watter ander sport(e) neem jy deel?
- How many hours do you play the other sport(s)? / Hoeveel uur neem jy deel aan die ander sport(e)?

- Do you exercise or do stretches on your own? / Doen jy enige oefeninge of strekke op jou eie? (choice/keuse =Yes/No/Ja/Nee)
- Please specify the stretch or exercise / Watter strekke /oefeninge rig jy uit?
- How many hours of exercises or stretches do you do per week? / Hoeveel uur se oefen of strekoefeninge voer jy per week uit? (choice/keuse=Yes/Ja/No/Nee)
- What is your racquet hand placement? / Wat is jou handposisie op jou rakket? (Grip/Greep) (choice/keuse=eastern, continental, western, semi western, not sure/nie seker nie)
- Where did you learn this specific racquet hand placement? / Waar het jy die rakket-posisie of -greep geleer? (choice/keuse=self, parents/ouers, coach/afrigter, other/ander) If other, please specify. / Indien ander, spesifiseer asseblief.
- What racquet type do you use? / Watter tipe rakket gebruik jy?
- What grip type do you use? / Watter tipe greepproduk gebruik jy?
- Have you experienced any lower back pain in the last month? / Het jy enige lae rugpyn in die afgelope maand ervaar? (choice/keuse=Yes/Ja/No/Nee)
- What happened? / Wat het gebeur?
- Please give a number for your pain out of 10. See picture. / Gee asseblief 'n nommer vir jou pyn uit 10. Sien prentjie.
- Have you experienced any back pain in the last six months? / Het jy enige lae rug pyn in die afgelope ses maande ervaar? (choice=Yes/No)
- Please give a number for your pain out of 10. See picture. / Gee assebleif 'n nommer vir jou pyn uit 10. Sien prentjie.
- What happened? / Wat het gebeur?
- Have you experienced any other injuries in the last month? / Het jy enige ander beserings in die afgelope maand opgedoen? Specify. / Spesifiseer asseblief. (choice/keuse=Yes/Ja/Nee/No)
- Have you experienced any other injuries in the last six months? / Het jy enige ander beserings in die afgelope ses maande opgedoen? Specify. / Spesifiseer asseblief. (choice/keuse=Yes/Ja/No/Nee)
- Did you have to stop practice/play due to an injury in the last six months? / Moes jy binne die afgelope ses maande as gevolg van ’n besering jou spel staak? Please explain. / Verduidelik asseblief. (choice/keuse=Yes/Ja/No/Nee)
- Where was the injury? / Waar was die besering?

- What happened? / Wat het gebeur?
- What type of injury was this? / Watter tipe besering was dit? (choice/keuse=Acute/Akuut, Overuse /Oorgebruik/misbruik; Recurrent/ herhalend of te veel gebruik, Traumatic/Traumaties)

Thank you for completing the questionnaire/Dankie vir die invul van die vraelys.

APPENDIX II: Physical Testing Recording Sheet

Participant No		Dominant arm		Dominant leg	
ROM		**T12/L1**	**T12/L1**	**L5/S1**	**L5/S1**
Thoracolumbar Flexion					
Thoracolumbar Extension					
Lx Lateral Flexion		R		L	
TxLx Rotation		R		L	
Hip Internal Rotation		R		L	
Hip External Rotation		R		L	
Body Measurements					
Weight (kg)					
Head to Toe (height cm)					
Heel to Toe (foot size cm)					
Finger to Finger (arm span cm)					
Floor to Medial Malleolus (ankle height cm)					
Floor to Greater Trochanter (hip height cm)					
ASIS to ASIS (hip width cm)					
Floor to Lateral Epicondyle (knee height cm)					
Left to Right Acromion (shoulder width cm)					
Inner sole of middle foot (sole height cm)					
ASIS to lateral malleolus (leg length cm) R					
ASIS to lateral malleolus (leg length cm) L					

SEBT	RAM/LAM	RA/LA	RAL/LAL	RL/LL	RPL/LPL	RP/LP	RPM/LPM
SEBT 1 R (cm)							
SEBT 1 L (cm)							
SEBT 2 R (cm)							
SEBT 2 L (cm)							
SEBT 3 R (cm)							
SEBT 3 L (cm)							

SERVE	Score (/5)
Serve 1	
Serve 2	
Serve 3	
Serve 4	
Serve 5	
Serve 6	

ROM – range of motion; Lx – lumbar; TxLx – thoracolumbar; R – right side; L – left side; ASIS – anterior superior iliac spine; SEBT – Star Excursion Balance Test; RAM – right anteromedial reach; LAM – left anteromedial reach; RA – right anterior reach; LA – left anterior reach; RAL – right anterolateral reach; LAL – left anterolateral reach; RL – right lateral reach; LL – left lateral reach; RPL – right posterolateral reach; LPL – left posterolateral reach; RP – right posterior reach; LP – left posterior reach; RPM – right posteromedial reach; LPM – left posteromedial reach.

APPENDIX III: Ethical Clearance Certificate

R14/49 Mrs Elandie Elizabeth Immelman

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M161121

NAME: (Principal Investigator)	Mrs Elandie Elizabeth Immelman
DEPARTMENT:	School of Therapeutic Sciences, Department of Physiotherapy North Gauteng Tennis Club
PROJECT TITLE:	Lower Quarter Muscle Activation in Adolescent Tennis Players with and without Lower Back Pain
DATE CONSIDERED:	25/11/2016
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Benita Olivier
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	10/02/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 301, Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed in November and will therefore be due in the month of November each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

Date 11/02/2017

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX IV: Information Sheet – Participant and Parent/Guardian

Physiotherapy

Faculty of Health Sciences · Private Bag 3, Wits, 2050, South Africa
Tel: +27 11 717 2014 · Fax: + 27 86 663 5776 · E-mail: benita.olivier@wits.ac.za · Staff profile:
http://www.wits.ac.za/staff/benita.olivier.htm

INFORMATION DOCUMENT: Tennis Player

Dear Tennis Player

I am currently doing a research project on the muscles that are activated during the tennis serve and other exercises in young tennis players.

Research is just a process which is used in learning to find the answer to a question. In this study, we want to learn which muscles are activated, and at what time, during the serve, in players with and without lower back pain. We also want to learn which exercises activate the same muscles. Tennis is a fascinating sport that is internationally celebrated. As a health care provider, I feel it is very important to promote the correct care in order for players to give of their best on the court. Through this research project we could possibly identify risk areas for injury. This could help tennis players to prevent injury to the lower back from a young age.

I would really appreciate it if you would be willing to participate in this research project. The data collection is scheduled to start in March 2017 and finish towards the end of 2017. We require tennis players with and without lower back pain.

Who is eligible to take part in this study?

- Male and Female tennis players between the ages of 10 and 18 years.
- Tennis players at the North Gauteng Club that play tennis at least once a week and have played tennis for at least three years.

Who cannot take part in this study?

- If you have recently suffered from other acute injuries that will affect your tennis serve (for example an acute ankle sprain).
- If you have a metabolic condition or genetic disorder that could affect your muscle activation (for example Diabetes).
- If you have undergone previous back surgery, spinal tumours or spinal infection.
- If a Medical Doctor has diagnosed you with Scheuermann`s disease, Ankylosing spondylitis, Spondylolysis and/or Spondylolisthesis.
- If you are uncertain whether you have any of these conditions, do not hesitate to contact me for more information.

What is involved in the study?

Phase one: You will be asked to complete a questionnaire. This can be done at home. The questionnaire will include questions such as: age, gender, previous injury, type of training and exercise, type of racquet, type of grip, etc.

Phase two: Testing will be done during a pre-arranged meeting that will suit you, your parents and the coach. The testing procedure will include a range of motion tests, exercise/balance tests and the serve motion.

- Testing will be done with a motion sensor suit that will pick up the movements during testing. Here is an example of the suit (see image).



- Testing will be done with your own tennis shoes on and with your own racquet.
- Electromyography (EMG) involves wireless sensors being placed on your muscles that will give us a reading of the electrical activity produced by the muscles. Your skin will be cleaned and wireless EMG sensors will be attached to your stomach and lower back. This will enable us to get a reading of which muscles are activated during the specific movements. This will be done in a closed-off area for privacy.
- Once the EMG sensors have been applied, you will be asked to do a balance exercise and the service motion ten times. Muscle activity and motion will be recorded on a computer.
- Video footage will be taken in order to obtain a reference point for analysis. The video footage will only be used as a guiding factor to correlate muscle activation findings with the phase of the serve motion or exercise (for example the acceleration phase during the serve). You will be filmed from behind, with no identifying features.
- The entire testing procedure should not take more than an hour. Testing will be done at the North Gauteng Tennis Club. The first 50 confirmed respondents will be contacted and included in phase two. You will receive your movement video that will enable you to analyze your tennis serve.

Participation is voluntary and refusal to participate will not involve any penalty or loss of benefits to which you are otherwise entitled. You may withdraw from this study at any time without suffering any repercussions.

Are there any risks in taking part in this study?
Your will not be exposed to any additional risks other than the risks that you are normally exposed to when you are involved in tennis training or playing.

What are the benefits of taking part in this study?
Your muscle activity and movement during the service motion will be measured and the results emailed to you and/or your parents. I will not make recommendations to improve your service technique. However, if you are interested, I will give you the videos of your service which will allow you to analyse your technique. Non-

identifiable, generalised results will be made available to all of the participants at the end of the study. No monetary award will be given for taking part in this study.

Will information be handled as confidential?
Efforts will be made to keep personal information confidential according to the POPI Act. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law. To ensure the confidentiality of the participants, each tennis player will be assigned a study number. The key to the study numbers assigned will be kept by the researcher only. Names of participants are only to be written on the consent form. Additionally, consent forms will be kept separate from the data collected. All information will be used only for the purpose intended in this study.

For further information, you are welcome to contact me on 0828395153 or send an email to elandiedb@gmail.com, subject: tennis study.

For more information on, or for the reporting of ethical concerns, you may contact the chair of the Human Research Ethics Committee of the University of the Witwatersrand:
HREC (Medical) contact details: Prof P Cleaton Jones, Tel 011 717 2301, email peter.cleaton-

jones1@wits.ac.za. Ms Z Ndlovu/ Mr Rhulani Mkansi/ Mr Lebo Moeng Administrative Officers 011 717

2700/2656/1234/1252 Zanele.ndlovu@wits.ac.za; Rhulani.mkansi@wits.ac.za; and

Lebo.moeng@wits.ac.za.

Thank you for considering this study. Your contribution is much appreciated.

Kind regards

Elandie Immelman
Physiotherapy Department
University of the Witwatersrand

Physiotherapy

Faculty of Health Sciences · Private Bag 3, Wits, 2050, South Africa
Tel: +27 11 717 2014 · Fax: + 27 86 663 5776 · E-mail: benita.olivier@wits.ac.za · Staff profile:
http://www.wits.ac.za/staff/benita.olivier.htm

INFORMATION DOCUMENT: Parent/Guardian

Dear Parent/Guardian

I am currently doing a research project on the muscles that are activated during the tennis serve and other exercises in young tennis players.

Research is merely a process used in learning to find the answer to a question. In this study, we want to learn which muscles are activated, and at what time during the serve, in players with and without lower back pain. We also want to learn which exercises activate the same muscles. Tennis is a fascinating sport that is internationally celebrated. As a health care provider, I feel it is very important to promote the correct care in order for players to give of their best on the court. Through this research project we could possibly identify risk areas for injury. This could help tennis players to prevent injury to the lower back from a young age.

I would really appreciate it if you would be willing to allow your child to participate in this research project. The data collection is scheduled to start in March 2017 and will finish towards the end of 2017. We require tennis players with and without lower back pain.

Who is eligible to take part in this study?

1. Male and Female tennis players between the ages of 10 and 18 years.
2. Tennis players at the North Gauteng Club that play tennis at least once a week and who have played tennis for at least three years.

Who cannot take part in this study?

- If your child has recently suffered from other acute injuries, that will affect his/her tennis serve (for example an acute ankle sprain).
- If your child has a metabolic condition or genetic disorders that could affect his/her muscle activation (for example Diabetes).
- If your child has undergone previous back surgery for spinal tumours or spinal infection.
- If a Medical Doctor has diagnosed your child with Scheuermann`s disease, Ankylosing spondylitis, Spondylolysis and/or Spondylolisthesis.
- If you are uncertain whether your child has any of these conditions, do not hesitate to contact me for more information.

What is involved in the study?

Phase one: Your child will be asked to complete a questionnaire. This can be done at home. The questionnaire will include questions such as: age, gender, previous injury, type of training and exercise, type of racquet, type of grip, etc.

Phase two: Testing will be done during a pre-arranged meeting that will suit you, your child and the coach. The testing procedure will include a range of motion tests, exercise/balance tests and the serve motion.

- Testing will be done with a motion sensor suit that will pick up the movement during testing. Here is an example of the suit (see image).



- Testing will be done with your child`s own tennis shoes on and with his/her own racquet.
- Electromyography (EMG) involves wireless sensors placed on his/her muscles that will give us a reading of the electrical activity produced by the muscles. Your child`s skin will be cleaned and wireless EMG sensors will be attached to his/her stomach and lower back. This will enable us to get a reading of which muscles are activated during the specific movements. This will be done in a closed-off area for privacy.
- Once the EMG sensors have been applied, your child will be asked to do a balance exercise and the service motion ten times. The muscle activity and motion will be recorded on a computer.
- Video footage will be taken in order to obtain a reference point for analysis. The video footage will be used only as a guiding factor to correlate muscle activation findings with the phase of the serve motion or exercise (for example the acceleration phase during the serve). Your child will be filmed from the back, with no identifying features.
- The entire testing procedure should not take more than an hour. Testing will be done at the North Gauteng Tennis Club. The first 50 confirmed respondents will be contacted and included in phase two. Your child will receive his/her movement video that he/she can use to analyze his/her tennis serve.

Participation is voluntary and refusal to participate will not involve any penalty or loss of benefits to which you or your child are otherwise entitled. You may withdraw your child from this study at any time without suffering any repercussions.

Are there any risks in taking part in this study?
Your child will not be exposed to any additional risks other than the risks that they are normally exposed to when they are performing tennis training or playing.

What are the benefits of taking part in this study?

Your child`s muscle activity and movement during the service motion will be measured and emailed to him/her and/or you. I will not make recommendations to improve your child`s service technique. However, if you are interested, I will give you the videos of your child`s serve which will allow you to analyse his/her technique. Non-identifiable, generalised results will be made available to all participants at the end of the study. No monetary award will be given for taking part in this study.

Will information be handled as confidential?
Efforts will be made to keep personal information confidential according to the POPI Act. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law. To ensure the confidentiality of the participants, each tennis player will be assigned a study number. The key to the study numbers assigned will be kept by the researcher only. The names of the participants are to be written only on the consent form. Additionally, consent forms will be kept separate from the data collected. All information will be used only for the purpose intended in this study only.

For further information, you are welcome to contact me on 0828395153 or send an email to elandiedb@gmail.com, subject: tennis study.

For more information on, or for the reporting of ethical concerns, you may contact the Chair of the Human Research Ethics Committee of the University of the Witwatersrand:
HREC (Medical) contact details: Prof P Cleaton Jones, Tel 011 717 2301, email peter.cleaton-

jones1@wits.ac.za. Ms Z Ndlovu/ Mr Rhulani Mkansi/ Mr Lebo Moeng Administrative Officers 011 717

2700/2656/1234/1252 Zanele.ndlovu@wits.ac.za; Rhulani.mkansi@wits.ac.za; and

Lebo.moeng@wits.ac.za.

Thank you for considering this study. Your contribution is much appreciated.

Kind regards

Elandie Immelman
Physiotherapy Department
University of the Witwatersrand

APPENDIX V: Consent Forms – Participant and Parent/Guardian

CONSENT TO PARTICIPATION: Tennis Player Assent Form

PLEASE FILL IN TENNIS PLAYER

I_____, **the tennis player,** hereby agree to participate in the study as described to me in the information sheet. I hereby agree to complete the required questionnaire, give consent for the application of wireless EMG sensors and to the EMG recording during the exercises and serve motion. I understand that the results and video footage will be kept confidential.

I am aware that I will not be exposed to any additional risks other than those usually experienced during tennis playing and that I can withdraw from the study at any time without suffering any repercussions. I understand that there are no monetary rewards for my participation, that participation is voluntary, and that I am not in any way obliged to take part.

Name of participant:	
Date of Birth:	
Email of participant:	
Cell number of participant:	

If you give consent that you understand and accept the above mentioned, please sign here:

Signature of Tennis Player _____ Date _____

Signature of Researcher _____ Date _____

CONSENT TO VIDEO FOOTAGE:

I understand that the video footage will be used as a guiding factor to correlate muscle activation findings with the phase of the service motion or exercise.

- The video footage will be used only for research purposes by the principal investigator.

- The video footage will be taken from behind the participant, with only the allocated study number on the back, and no personal identifying features.
- The video footage will be taken of the range of motion testing, exercises and service motion, and NOT during the placement of the EMG sensors.
- The video footage will be saved and kept confidential by the principal investigator.
- If you would like the camera to be turned off at any stage, please tell the investigator. You may change your mind at any stage.
- If you would like a copy of the video recording, please inform the principal investigator.

If you give consent that you understand and accept the above-mentioned, please sign here:

Signature of Tennis Player _____ Date _____

Signature of Researcher _____ Date _____

Thank you very much for your participation.

CONSENT TO PARTICIPATION: Parent/Guardian

PLEASE FILL IN PARENT/GUARDIAN

I, _____, **the parent/guardian** hereby agree for my child, _____ (name of child), to participate in the study as described to me in the information sheet. I hereby agree for him/her to complete the required questionnaire. I give consent for the application and recording of wireless EMG sensors and a motion sensor suit during the exercises and serve motion of my child. I understand that the results and video footage will be kept confidential.

I am aware that he/she will not be exposed to any additional risks other than those usually experienced during tennis playing and that he/she can withdraw from the study at any time without suffering any repercussions. I understand that there are no monetary rewards for his/her participation and that participation is voluntary.

Name of Parent/Guardian:	
Email of Parent/Guardian:	
Cell number of Parent/Guardian:	

If you give consent that you understand and accept the above mentioned, please sign here:

Signature of Parent/Guardian _____ Date _____

Signature of Researcher _____ Date _____

CONSENT TO VIDEO FOOTAGE:

I understand that the video footage of my child will be used as a guiding factor to correlate muscle activation findings with the phase of the service motion or exercise.

- The video footage will be used only for research purposes by the principal investigator.
- The video footage will be taken from behind the participant, with only the allocated study number on the back, and no personal identifying features.
- The video footage will be taken of the range of motion testing, exercises and service motion and NOT during the placement of the EMG sensors.
- The video footage will be saved and kept confidential by the principal investigator.
- If your child would like the camera to be turned off at any stage, he/she should please tell the investigator. Your child may change his/her mind at any stage.
- If you or your child would like a copy of the video recording, please inform the principal investigator.

If you give consent that you understand and accept the above-mentioned, please sign here:

Signature of Parent/Guardian _____ Date _____

Signature of Researcher _____ Date _____

Thank you very much for your child's participation.

APPENDIX VI: Indemnity Form – Parent/Guardian

UNIVERSITY OF THE
WITWATERSRAND
JOHANNESBURG

Acknowledgement of Limitation of Liability
Legal Declaration of Indemnity,

Name: .....

Address: .....

.....

Tel: .....(Home) .....(Cell) .....(Work)

1. I acknowledge and declare that I understand that:
   - 1.1 I have granted permission for my child/ward [name] ..... to participate in the research project on muscles that activate during the tennis serve and other exercises, in young tennis players developed by Ms Elandie Immelman (hereinafter "the Study") on ..... 201....., at the.....
   - 1.2 the University of the Witwatersrand, Johannesburg (hereafter referred to as "the University") has insured itself for its liability arising from the acts and omissions of persons acting on its behalf, and that its registered students, staff and individuals who are subject to the University's, rules, regulations, policies, procedures and standing orders as amended from time to time are insured during the course and scope of their registered courses and/or within the scope of University business. This is subject to the proviso that the University's maximum liability will be limited, whether for a single or multiple events, to the extent that it is covered therefor.
   - 1.3 in cases where no fault can be attributed to the University, I hereby indemnify, absolve and hold harmless the University, its officials, employees, students and invitees in respect of any damage to the property, death or bodily injury to/of myself, my child/ward and/or third parties, whether on/off the University precincts, or whilst engaged in any activity related to the University; and
   - 1.4 my child/ward will attend the Study at my own risk where the event falls outside the cover provided to or by the University.
   - 1.5 I must inform the University as soon as I become aware of any claim/ anticipated claim and will provide the University with all the necessary information.

2. I acknowledge that I have read and understood the contents of this Legal Declaration of Indemnity, in every respect.

Signed at.....on this the.....day of .....201.....

_____ _____

Signed: Parent/Guardian Signed: Witness