CORE STABILITY AND ATHLETIC PERFORMANCE AMONG UNIVERSITY ATHLETES

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ABSTRACT

Key words: Core stability, Athletic performance, Double leg lowering test, University athletes, Rugby, Hockey, Cricket, Basketball, Soccer, Males, Females

Background: Information about the contribution of core stability to athletic performance is still limited although it has been suggested to be an important factor. Thus, questions remain about the mechanisms of core stability, its measurement and its correlation with athletic performance in different types of sport.

Objectives: To determine and describe the relationship between core stability and athletic performance measures in male and female university athletes.

Methods: Hundred and twenty-five (125) male and fifty-two (52) female first team Kovsie athletes participating in rugby, hockey, cricket, basketball and soccer underwent five performance tests: the double leg lowering test (DLLT) to measure core stability, the forty-meter sprint test, the T-test, vertical jump and a medicine ball chest throw. All athletes performed three trials of each test in a randomized order. Correlations between the DLLT and each of the four performance tests were determined overall and separately by gender and sport. Furthermore, the effect of core stability on athletic performance measures was assessed using ANCOVA, fitting the factors sport and gender and the covariates age, height, weight, BMI and fat% of the athletes, as well as relevant interaction terms.

Results: This study suggests that in the overall sample (both genders and all sports) all correlations between core stability (DLLT) and the performance tests were small ($r<0.3$). However, when the different sports were considered separately, for basketball players there were very large to large correlations between core stability (DLLT), the vertical jump ($r=0.75$) and chest throw ($r=0.64$).

When stratified by gender: In females, overall for all sports, there were large correlations between core stability (DLLT), the vertical jump ($r=0.67$) and chest throw ($r=0.53$). However, when the different sports were considered separately, for basketball players, there were very large to large correlations between core stability (DLLT), the vertical jump ($r=0.87$), chest throw ($r=0.76$) and forty-meter sprint ($r=-0.53$). All of the other sports reflected small to moderate correlations between core stability (DLLT) and athletic performance.

In males, overall for all sports, there were only small correlations between core stability (DLLT) and all the performance tests ($r<0.2$). However, when the different sports were considered separately, for basketball players there were large correlations between core stability (DLLT), the vertical jump ($r=0.60$) and chest throw ($r=0.59$). Furthermore, for soccer players there were large correlations between core stability (DLLT) and both the forty-meter sprint ($r=0.58$) and T-test ($r=0.58$); however, these correlations suggest a decrease in performance with increasing core stability (DLLT), since they are positive. Cricket players also revealed a large correlation between core stability (DLLT) and vertical jump ($r=-0.51$); however, this correlation also suggests a decrease in performance with increasing core stability (DLLT), since it is negative.

When body fat percentage is considered, it is clear that body composition varies according to the type of sport. Overall (both genders and all sports), the study suggest very large to correlations between body fat percentage and the performance tests, T-test ($r=0.67$), forty-meter sprint ($r=0.74$) and vertical jump ($r=-0.69$). When the different sports were considered separately the results look similar; however, hockey ($r=-0.51$) and soccer ($r=-0.54$) also show a significant large correlation between the chest throw and body fat percentage ($p<0.05$). When stratified by gender: Overall, in females the results show large correlations between core stability, the T-test ($r=0.55$) and forty-meter sprint ($r=0.61$); whereas in males, these correlations are only small to moderate.

Conclusion: The association between core stability (DLLT) and athletic performance appears to be weak in the overall sample, that is, when the factors gender and in particular type of sport are ignored; however, when correlations are considered separately, for the two genders and for the various types of sport, some large and very large correlations between core stability (DLLT) and specific performance tests can be identified. Thus, basketball players show large and very large correlations between core stability (DLLT) and both the vertical jump and chest throw. This study can serve as the basis of future research on the role of core stability (DLLT) in optimal performance in different sports; to the results of such research assist coaches and athletes with the development of training guidelines that enhances athletes' performances. Ideally sport specific tests will be able to better define and to examine the correlation of core stability with performance.

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LIST OF ABBREVIATIONS

ADIM	**Abdominal drawing in Maneuver**
ALAW	**Anterolateral Abdominal Wall**
ASIS	**Anterior Superior Iliac Spine**
ASLR	**Active straight leg raise**
BD	**Bone density**
BLS	**Basic life support**
BMI	**Body mass index**
BOS	**Base of support**
BP	**Blood pressure**
BPC	**Blood pressure cuff**
CLBP	**Chronic lower back pain**
cm	**Centimetres**
DLLT	**Double leg lowering test**
EMG	**Electromyography**
EO	**External Oblique muscle**
ES	**Erector Spinae muscle**
ETST	**Endurance trunk stability test**
FHS	**Faculty of Health Sciences**
GLM	**Generalized linear model**
GLM SELECT	**Generalized linear model select**
GM	**Global mobilizers**
GS	**Global stabilizers**
GSS	**Global stabilization system**
HMS	**Human Movement Sciences**
HP	**High performance**
HPCSA	**Health Professions Council of South Africa**
HSREC	**Human Science Research Ethical Committee**
IAP	**Intra-abdominal pressure**
ICC	**Intra-class correlation coefficient**

IO	**Internal Oblique muscle**
IQR	**Inter-quartile range**
ISAAC	**International Standards for Anthropometric Assessment**
kg	**Kilogram**
Kg.m^2	**Kilogram per square meter**
LS	**Local stabilizers**
LSS	**Local stabilization system**
m	**Meter**
NCCA	**National Collegiate Athletic Association**
NMC	**Neuro-muscular control**
PEET	**Prone extension endurance test**
PFM	**Pelvic Floor muscles**
QL	**Quadratus Lumborum**
RA	**Rectus Abdominis muscle**
ROFD	**Rate of force development**
ROM	**Range of motion**
SAID	**Specific adaptation to imposed demands**
SAS	**Statistical Analysis Software**
SBC	**Schwarz Bayesian Information Criterion**
sec	**Seconds**
SFET	**Side flexion endurance test**
SLR	**Straight leg raise**
SSC	**Sport Science Centre**
STD	**Standard deviation**
TLF	**Thoracolumbar fascia**
TrA	**Transverse Abdominis muscle**
TST	**Trunk stability test**
UHBET	**Unilateral hip bridge endurance test**
UFS	**University of the Free State**
YBT	**Y-balance test**
yr	**Year**

TERMS AND DEFINITIONS

Active structures	**Include all the muscles of the body**
Anterior	**Front**
Antropometrist	**Specialist in anthropometry**
Biokineticist	**Exercise therapist/specialist**
Calf	**Muscle of the lower leg**
Distal	**Situated away from the point of attachment**
Double leg lowering test	**A test measuring abdominal strength, which served as the test for core stability**
Dynamic posture	**Posture when carrying out movements**
Extension	**Bending increasing range of motion angle**
Flexion	**Bending decreasing range of motion angle**
Gluteus	**Muscles of the buttocks**
Iliac crest	**Crest of the Ilium (largest bone of the pubis)**
Iliocristale	**Muscle above the iliac crest on the most lateral side**
Inferior	**Lower in position**
Inguinal fold	**The location where the caudal end of the urogenial ridge joins the anterior abdominal wall**
Inter-quartile range	**The difference between the third and first quartile of a box plot in statistics**
Isometric contraction	**Contraction where the tension in the muscle increases but the length of the muscle stays the same**
Lateral	**Side**
Longitudinal	**Diagonal**
Lower extremities	**Legs**
Neutral position	**The position of bones and ligaments in such a manner where it allows for optimal movement and minimal stress**
Neutral zone	**Small range of intervertebral motion near the joint's neutral position where minimal resistance is offered by the osteoligamentous structures**
Omphalion	**Midpoint of Navel**
Para Umbilicus	**Muscle complex next to the Navel**

Passive structures	**Include the bone, ligaments, osseous ligamentous structures and fascia of the body**
Patella	**Knee cap**
Posterior	**Back**
Prime movers	**Main muscles responsible for limb movement**
Proximal	**Situated closest to the point of attachment**
Spinal Segment	**Vertebral body**
Static posture	**Posture when standing still**
Sub scapularis	**Muscle covering the scapula**
Superior	**Higher in position**
Thigh	**Muscle of the upper leg**
Triceps	**Muscle at the back of the arm**
Upper extremities	**Arms**
Vertec	**Equipment for measuring vertical jump height**
VO_2 max	**Maximum volume of oxygen you can oxidize from the blood during aerobic exercises per kilogramme body weight per minute (ml/kg/min)**

CORE STABILITY AND ATHLETIC PERFORMANCE AMONG UNIVERSITY ATHLETES

CHAPTER 1

FRAMEWORK OF STUDY

1.1 INTRODUCTION TO CORE STABILITY

Sport can still be seen as a shared interest among all members of a community and popular demand for entertainment within our era, whereas physiological parameters for various sport types seem to differ less among top athletes, it can be remarked that their training programmes receive more attention to detail and specific training modalities. The main reason for accentuation to core stability training in the elite sporting industry, is the fundamental role it plays in athletic performance and the belief that it could prevent the risk of injury (Hodges & Richardson, 1998:46; Kibler *et al.,* 2006:193).

Even though core stability is defined differently by several authors, most of them accentuate the trunk, with exceptional importance to the lumbo-pelvic region (Willardson, 2007:979; Haugen *et al.*, 2016:1). Athletic activities require good and proper arm and leg movements in order to ensure optimal performance; therefore, the body should be able to generate force to produce movement, but equally important - should be able to absorb these forces through various muscles that activate to stabilize the trunk (Sharrock *et al.*, 2011:65). Panjabi (1992(a):383), further elaborated the stability system and divided it into three groups, namely: the passive structures that consist of all the bones and ligaments; the active structures that consist of all the surrounding muscles; and lastly, all the neural structures. During sport activities, various structures assist with force development that originate from the lower extremities and continue through the core to the arms to ensure movement (Kibler, 1996:79). As stated by Cordo and Nashner (1982:287), speedy arm movement has a specific neuromuscular activation response in order to decelerate the arm, starting from the lower extremities, progressing through the trunk, to the upper extremities. This neuromuscular activation response is important in various sports such as tennis, kicking and baseball activities.

According to literature, the term core stability and core strength are two separate terms in the rehabilitation and athletic sector, yet are sometimes used as one interchangeable concept (Hibbs *et al.* 2008:996). Core stability, on the one hand, is " the ability to control the position and the motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segment in integrated athletic activities" (Hibbs *et al.*, 2008:996; Gamble, 2013:136; Silfies *et al.*, 2015:361), while core strength is related to the force produced when muscles are contracting - causing the pressure of the intra-abdominal area to increase and maintain the force (Reed *et al.*, 2012:698). The core is made up of twenty-nine muscles attaching to the pelvis, including: the spinal column, hip joints and part of the lower extremities (Gamble, 2013:136; Silfies *et al.*, 2015:362). Even though literature states that much of the hip musculature attaches to the core and its fundamental role of connecting the lower extremities to the core is noted, Borghuis *et al.* (2008:913), identified that it should not be considered as part of core stability as a whole. However, Reed *et al.* (2012:702), tested athletes who completed a core program indicating an improved running time over a 5000 meter with more than 47 seconds. It is also believed that the gluteus medius assists with trunk stabilization when the leg is fixed to ensure power supply for leg motions during activities such as running or throwing (Putnam, 1993:125).

In totality, core stability strengthens the structures that are involved in different sporting movements such as swimming, running, catching, throwing and rowing; by carrying over the kinetic energy from the core to the extremities, keeping the body in equilibrium and allowing a platform for distal body parts to complete their function (Kibler *et al.*, 2006:189; Borghuis *et al.*, 2008:901). Therefore, as stated above, we can conclude that no athletic activity is possible without some degree of stability.

Although inconsistency about the definition of the core exists, it does not detract from the common acceptance of the significance of our central muscles in developing efficient movement (Borghuis *et al.*, 2008:896; McGill, 2010:33; Okada *et al.*, 2011:252). The core needs to be well trained and conditioned in order to provide the required stability, because it is seen as one of the fundamental aspects enabling movement production required in various sport activities (Coetzee *et al.,* 2014:39).

Nevertheless, Haugen *et al.* (2016:2), raised the question whether or not high-performance athletes implement core training and suggested that numerous studies that have been completed, do not measure the exact volume of core training that has been performed (Ebben *et al.,* 2004:889; Fiskerstrand & Seiler, 2004:303; Orie *et al.*, 2014:93; Tonnessen *et al.*, 2016:643). The recorded quantities documented by authors mentioned in the previous study varied from five minutes to two hours per week. Haugen *et al.* (2016:2) also stated that although core stability training is not the most important modality in any sport training program, most high-performance athletes execute core exercises to some degree. It has also been found that core stability training most likely occurs during preparation periodization phases rather than during competition periodization phases and an even higher occurrence has been noted during rehabilitation phases in order to prevent injuries or to condition the athlete when they are not allowed to continue with their original program due to injury (Puentedura & Louw, 2012:123).

Hodges and Moseley (2003:367) concluded that, in some cases, core training also reduce back pain by assisting motor control, preventing improper training techniques during sport-specific movements. Improper movements can cause injuries because athletes tend to overlook the role of proper stability - putting surrounding structures under tremendous stress (Akuthota & Nadler, 2004:88). During training, most trainers do not focus on correcting faulty posture or instability - which can possibly lead to injury and pain when not addressed with caution (Borghuis *et al.*, 2008:904). Thus, in order to improve load or to adjust a program to improve performance, it is important to eliminate the factor causing the pain. To use an example: when the back is too rigid and cannot tolerate flexion, athletes try to ease the pain by pulling up their knees, causing more harm due to the deep tissue damage (Snook, 1998:18). Another example is when athletes stand with a slouch posture for a long time period, causing their muscles to be stiffened over the whole day until it can result in pain. Instead of relaxing the muscle by correcting posture to de-load the spine muscles, doctors prescribe anti-inflammatories rather than addressing the problem, so only treating the symptom and not the cause (Ebenbichler *et al.*, 2001:1892). This is an important motivation for trainers to have a good understanding of the body as a whole, to ensure they understand the conditioning and retraining of various structures to optimize movement.

In order to optimally train the core, trainers should completely understand stability in total. As stated by McGill, (2010:36) maintaining balance on a physio ball, does not address all the muscles necessary for spine stability, but merely enables athletes to balance. Even more so, when doing this exercise incorrectly, athletes compress the spine even more, causing more harm. Whereas exercises including the body blade - as an example - in a seated position, engages the whole core, thus improving stability (Moreside *et al.*, 2007:161). Furthermore, athletes with the desire to improve their performance should carefully consider the choice of the exercises they wish to perform (Haff & Triplett, 2016:448-449).

It is very important that the exercise does not exceed the athlete's ability to tolerate the load as this could cause injury or damage to the involved structures (Hibbs *et al*., 2008:1000). It is also important to ensure that the athlete has the capacity to complete a certain number of exercises without insisting to do more than he or she is able to endure (McGill, 2010:36). Therefore, in ensuring that each athlete's capability and abilities are known, it is essential to perform a thorough subjective and objective evaluation, including the static and dynamic posture analysis, range of motion (ROM), flexibility, strength, endurance, explosive power, speed and agility as well as a thorough background of each athlete's history (Akuthota & Nadler, 2004:89). It is equally important for trainers or coaches to correct static and dynamic abnormalities to prevent back pain or injury to any structures of the body (Frederickson & Moore, 2005:671). An example of this statement is to teach athletes to bend their knees when picking up a load from the floor or just to stand in an upright position rather than slouching (Chaffin, 2005:47).

Arnold *et al.* (2015:96), explains that core stability provides stability due to its central orientation that involves the upper and lower extremities by enhancing the neuro-muscular control (NMC) of the body to ensure effective somatic positioning and movement even in uneven terrains and as such reduces the risk of unwanted injuries (Sharrock *et al*., 2011:65). When the core itself is weak, underactive, tight or unbalanced, it can negatively influence the athlete's performance (Hibbs *et al.,* 2008:1002).

As confirmed by McCaskey (2011:2), proper core stability also resists dynamic forces while stabilizing and aligning the spine, the ribs and the pelvis in such a manner, that resist external forces, preventing related injuries to the spine or back (Borghuis *et al*., 2008:901). Hibbs *et al*. (2008:1002) also proclaim that a stronger core produces more power and better muscle recruitment of the upper and lower limbs as well as the shoulder muscles. This reduces the risk of injury and also improves athletic performance by developing better speed, power and agility (Tse *et al*., 2005:547). It is therefore accepted that core stability training is an important modality to be used by rehabilitation and athletic professionals (Akuthota & Nadler, 2004:91). The core should be trained at the right threshold to correct weakness in order to regain control to:

- Increase the ROM in the joints;
- Increase muscle extensibility;
- Advance joint stability;
- Better muscle performance;

- Optimize biomechanics during movement; and
- Prevent the risk of injury (Akuthota & Nadler, 2004:90; Hibbs, *et al*., 2008:1002).

Together with the results of performance enhancement, with regards to the correlation between injury and core stability, scientists found a high association between a lack of sufficient core stability and an increased risk of injury due to a lack of postural control, abnormal recruitment patterns of the associated trunk muscles and an interruption in muscle contraction and relaxation response after unloading of the trunk (Borghuis *et al.,* 2008:894; Silfies *et al.,* 2015:363).

It can thus be concluded that insufficient stability leads to uncontrolled movements that cause injury and decrease sport performance (Trampas, 2015:373). This is one of the main reasons core stability training is one of the most popular training modalities used by coaches, athletes and personal trainers in the sporting sector to enhance the athlete's physical ability in order to improve their performance.

1.2 PROBLEM STATEMENT

During the 21st century, scientists have significantly increased their background and knowledge, based on literature, with regards to the relationship between core stability and athletic performance. Numerous research studies have also been completed that underline the benefits of core stability training on injury prevention or performance, but in combination with other training modalities such as speed, power, strength and agility (Myer *et al.,* 2005:51). Although several studies have investigated core stability, none could provide the exact indication for guidelines and prescription, while differing considerations and arguments have been suggested (Haugen *et al.,* 2016:1). Very limited studies have presented scientifically based evidence on the correct quantification and volumes that core training exercise prescriptions should adhere to.

In various sports, core stability is seen as the focal point to most kinetic chains involved during activities taking place in that specific sport (Borghuis *et al*., 2008:901). It is therefore believed that proper core stability along with control and strength of the core, motion, balance and proprioception, can optimize all the chains involved during movement of the extremities and transfer the energy to the extremities and the distal body parts (Kibler *et al*., 2006:190). Athletic performance can be measured in numerous ways (Nadler *et al.*, 2002:15) and core stability seems to create a few advantages such as decreasing lowering back pain, to enhance performance by keeping the body in equilibrium while completing a movement or function. It is believed by Hibbs *et al.* (2008:1002), that the athlete wanting to compete on an elite level should also have hip and trunk stability to guarantee effective core stability and an increase in optimal performance.

For example, Vezina and Hubley-Kozey (2000:1370), found a stable increase in trunk stability after participation in a core programme along with a study compelled by Nadler *et al. (*2002:9), who completed a structured core strengthening programme that reported an increase in strength and a decrease in lower back injuries among National Collegiate Athletic Association (NCAA) Division 1 college athletes. Scientists also found core stability training as a preventative tool for injuries and enables people to do daily activities without any pain (Akuthota & Nadler, 2004:86; Kibler *et al*., 2006:196; Hibbs *et al*., 2008:995; Trampas *et al.,* 2015:373). A study by both Sharrock, *et al*. (2011:66) and Tse *et al.* (2005:551), reported that after completing an eight-week core programme, athletes improved their core endurance but their athletic performance remained the same.

From the previous statement it is clear that there are many conflicting results from studies that have been done comparing the effect of core stability training on performance. Furthermore Arnold *et al.* (2013:99), also suggested a strong relationship between the level of activation of the muscles of the trunk, balance and core stability. Equally important, a previous study completed by Borghuis *et al.* (2008:905), found that, poor balance during sporting activities that involves sitting on unstable surfaces strongly relates to a delay in the activation of muscles around the trunk during unexpected perturbation. Therefore, trunk muscle activation provides stability enabling a person to maintain their balance when completing activities or functions such as rowing, in an unstable environment.

Nonetheless, many other studies did not find a positive correlation between core stability and athletic performance (Borghuis *et al.,* 2008:913; Okada, *et al*., 2011:260). Most sports portray balance or force production components and some require the body to be symmetrical, but as believed by Hibbs *et al*. (2008:1002), the most important factor all sports require is core stability when performing movement in all the different movement planes. Although there is controversy if core stability can produce stronger, faster or better movements; athletes still incorporate core stability exercises into their daily programmes, because, as stated earlier, the torso is stabilized and controlled by the stability of the core, ensuring optimal movement through the limbs (Okada *et al.,* 2011:252). Therefore, to ensure tasks are carried out as efficiently and accurately as possible, the body should be able to keep itself stable and maintain a balance in the central point of the kinetic chain (Okada *et al.,* 2011:252).

While there are numerous valid and reliable tests to determine the effect of core stability training on physical wellbeing, there are many contrasting results to solidify the nature of correlation between core stability and athletic performance since no golden standard test have been set out to quantify core stability as it pertains to athletic performance (Sharrock *et al.*, 2011:73). Therefore, the study has been done to provide scientific results on the effects of core stability on athletic achievement. Thus, as suggested by Sharrock *et al*. (2011:73), this research study identified specific performance and core stability measures as it pertains to a wide variety of sport in order to provide clarity with regards to the relationship between these variables. This will provide beneficial information for trainers and coaches when prescribing exercise programmes to different individuals according to their individual needs. Further investigation should also strive to conclude if there are definite sub-categories of core stability, which are of utmost importance to permit for peak training and performance for specific sports.

1.3 RESEARCH AIM

The primary aim of the study was to determine and describe the relationship between core stability and athletic performance measurements in male and female university athletes.

1.4 THE OBJECTIVES OF THE STUDY

In order to achieve the main aim of this study, the following objectives will be pursued:

- To objectively evaluate the relationship between core stability and athletic performance amongst university athletes.
- To establish the relationship between core stability performance of male and female university athletes (in different sports).

1.5 THE OVERVIEW OF THE STUDY

This dissertation consists of seven chapters structured as follows:

- **Chapter 1** provides the background that is followed by the formulation of the aims and objectives of the study.
- **Chapter 2** consist of a literature review about core stability and athletic performance.
- **Chapter 3** is a discussion of the methodology used to conduct the study. The questionnaire design, population size and methods of collection are also discussed.
- **Chapter 4** is a summary of the results found during testing.
- **Chapter 5** is a collective discussion of the results.
- **Chapter 6** concludes the whole study and also summarizes the limitations followed by the recommendations and references to further studies.
- **Chapter 7** summarizes the reflection of the researcher during the research process.

1.6 ETHICAL ASPECTS

Participation in this study was voluntary and participants had the right to withdraw from the study at any time. The researcher obtained written informed consent from all participants (cf. Appendix E & F). An information document (cf. Appendix C & D) was also provided to each participant, which explained all the procedures, processes, risks and benefits of the study. The informed consent and information document was available in English and Afrikaans.

Before signing the consent form, the participant had full knowledge and understanding of components that formed part of the project. It was also the responsibility of the researcher to explain the information to the participants before they participated in the study. No financial compensation was offered for taking part in the study. The participants were informed, should the result of the study be published, it will be done by cohort identification. Participation was confidential. All data were collected on a sheet and was logged in on an Excel sheet. The results of all the tests were kept highly confidential by means of a computer password.

Ethical application was successful and approved by the Ethics Committee of the Faculty of Health Sciences, of the University of the Free State (UFS), with the reference number: UFS-HSD 2017-0088.

CHAPTER 2

LITERATURE OVERVIEW

2.1 INTRODUCTION

Core stability training has been used by many professional coaches due to the belief in the positive effect of a conditioned core on athletic performance (McGill, 2010:33). The function of the core is described by Borghuis *et al*. (2008:899), as the platform of proximal stability for distal mobility by allowing the transfer of forces to the extremities. As found, cycling mechanics are greatly influenced by core stability preventing injury by reducing pedalling forces on the knees (Sharrock *et al.,* 2011:66). During sport activities, various structures assist with force development that originate from the lower extremities and continue through the core to the arms to ensure movement (Kibler, 1996:79). As stated by Cordo and Nashner (1982:287), speedy arm movement has a specific neuromuscular activation response to decelerate the arm and starts from the lower extremities, progressing through the trunk to the upper extremities and is important in various sports such as tennis, kicking and baseball activities.

Silfies *et al.* (2015:361) and Borghuis *et al*. (2008:895), both state that the core comprises the active trunk musculature and the passive structures of the spine, thoracolumbar spine and pelvis, while Kibler *et al.* (2006:189), claim that the core consists of the spine, abdominal muscles, hips, pelvis and proximal lower extremities. Furthermore, Akuthota and Nadler (2004:86), described the core as a box where the gluteus serves as the rear side of the box, the diaphragm as the top of the box, the muscles of the pelvic floor along with the muscles of the hip girdle as the floor of the box and the abdominal muscles as the front of the box. It is believed that the gluteus medius assist with trunk stabilization when the leg is fixed to ensure power supply for leg motions during activities such as running or throwing (Putnam, 1993:125). Therefore we can conclude that the stronger the muscles, the faster they will be able to contract, the quicker the athlete can perform movement resulting in better performance. It is therefore important to comprehend the role of various muscles to understand the role each muscle and how it coordinates movement (Sharrock *et al*., 2011:65). In summary the core is seen as the powerhouse where all movement develops in the kinetic chain and is assisted by the muscles of the core to stabilize the spine (Borghuis *et al*., 2008:895). As can be noted, the core functions are highly diverse and their role in everyday sporting activities are claimed to be of vital importance.

Furthermore, Panjabi (1992(a):383), describes core stability as an intertwined combination among three different subsystems: the passive part of the spinal column and pelvis, all the active muscles of the trunk (pelvic girdle) and the control unit of the nervous system (cf. Figure 2.1). The combination of these subsystems provides control to the body by maintaining the intervertebral range where movement occurs - within a limit that is safe for individuals to carry out any form of activity. The spine is passively supported by structures such as ligaments, bones and fascia, as well as all the active muscles that provide postural stability during activities such as running, kicking or throwing (Hibbs *et al.,* 2008:1001). The active muscles play the most important role in keeping the spine stable, since they can assist with passive stability when the passive structures fail to do so (Ebenbichler *et al.,* 2001:1889). Co-contraction of various muscles helps to keep the trunk stable by resisting forces that are created during activities such as kicking, running or throwing and also connects the upper and lower extremities through the fascial system thus linking the stability of the upper and lower extremities to each other (Borghuis *et al.*, 2008:897). Therefore, injury or dysfunction of any of the above-mentioned structures can lead to an unstable lumbar spine causing abnormal biomechanics during movement, which can lead to injuries or which can increase the risk of incurring injuries (Ebenbichler *et al.*, 2001:1890; Borghuis *et al.*, 2008:897).

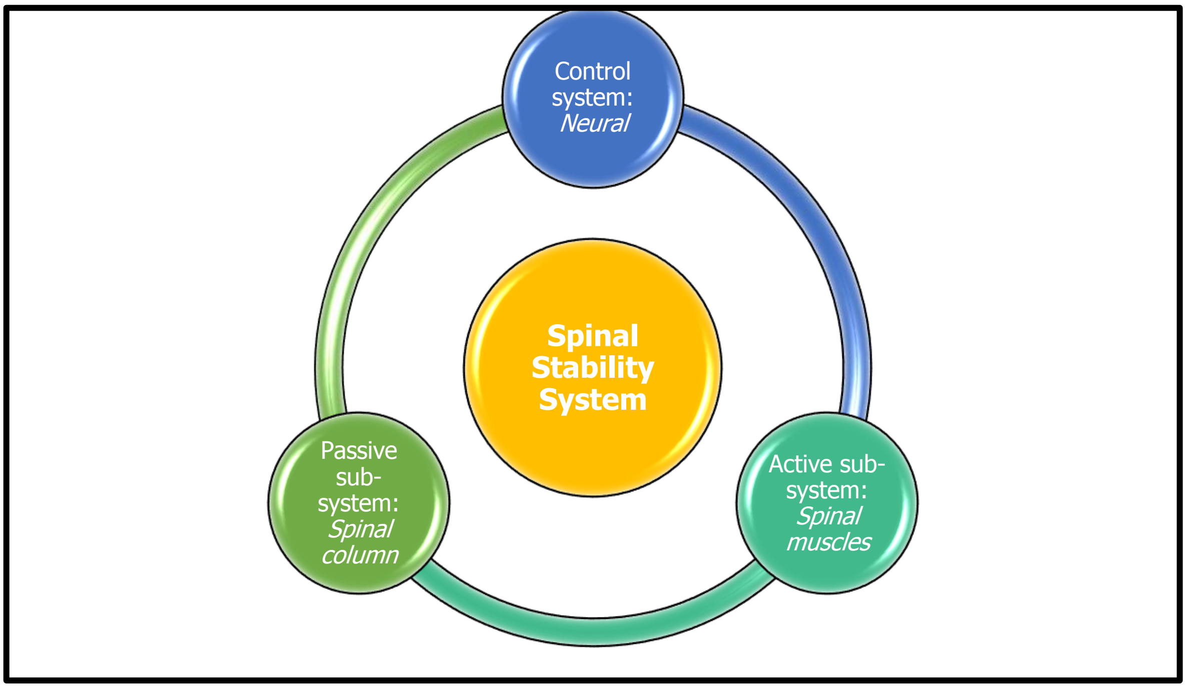

Figure 2.1: The spinal stability system (Panjabi, 1992(a):384)

2.2 ANATOMY OF THE CORE

2.2.1 Active and passive structures

As it has previously been mentioned, the core complex is formed of active and passive structures (Akuthota & Nadler, 2004:86; Kibler *et al.,* 2006:190).

The active structures are all the surrounding muscles, whereas the passive structures include the osseo-ligamentous structures and fascia (Hibbs *et al.,* 2008:998). To be able to maintain the correct muscle balance during movements, a strong core is essential in totality; and in order to obtain a strong core, McGill (2010:33), suggested that optimal recruitment patterns of the stabilizers, optimal length tension relationships between the muscles and optimal movement of the joints, ligaments and muscles in the hip joint are required. These elements provide NMC during the movement system, stability when performing movement, as well as effective deceleration and acceleration through the limbs (Sharrock *et al.*, 2011:65). It is stated by Borghuis *et al.* (2008:896), that stability is created by stiffness, thus stiffness around the hip joints, ligaments and surrounding structures of the hip girdle creates a very stable structure and increases non-linearly with activation of the trunk muscles. The trunk muscles have different functions and are seen as a very important component contributing to core stability (Hibbs *et al.,* 2008:997).

The thoracolumbar fascia (TLF) also forms part of the passive structures responsible for postural stability by connecting the lower limbs to the upper limbs (Borghuis *et al.*, 2008:898). This fascia consists of a lateral, anterior and posterior layer of connective tissue forming a band around the abdominals and lumbar spine to create a stabilizing corset (Willard *et al.,* 2012:508).

Likewise, muscles playing an important part in the core of the body include the abdominals (Huxel *et al.*, 2013:515). The abdominal muscle fibres are located around the abdomen and consist of the transversus abdominis (TrA), rectus abdominis (RA), external oblique (EO) and internal oblique (IO) (Ebenbichler *et al.*, 2001:1890). The TrA attach to the lateral and posterior layer of the TLF and when these muscles are contracted, the intra-abdominal pressure increases and stiffens the TLF (Kibler *et al.*, 2006:190). Along with the TrA, contraction of the EO and IO also increases the intra-abdominal pressure (IAP) that is formed through the fascia and as such forms a cylinder that increase lumbar stability before functional movements occur (Stokes *et al.*, 2011:799). The EO eccentrically controls the spine during lumbar extension and twisting movements whereas the RA causes trunk flexion and also braces the spine during high load activities such as lifting or pushing due to its high recruitment threshold (Akuthota & Nadler, 2004:87; Hibbs *et al.,* 2008:998;). The abdominals and obliques are muscles which are activated during direction specific patterns with regards to movement of the limbs and provide stability to the spine before any limb movements occur (Hodges, 1997:362; Borghuis *et al.*, 2008:898).

Thus, as stated by Kibler *et al*. (2006:190), the activation of the abdominals provides stiffness, stabilizes the spine and forms a solid base of support where motion can occur. The erector spinae (ES), intertransversii, multifidus and the rotators are muscles assisting with lumbar extension (Kibler *et al.,* 2006:190).

The ES are mainly responsible for lumbar extension due to their long moment arms, whereas the rotators and intertransversii act as length converters (Ebenbichler *et al*., 2001:1890). Lastly, the multifidus stabilize the spinal segments during upper limb or rotational movements due to its short moment arm (Akuthota & Nadler*,* 2004:87). Literature also states that the multifidus and abdominal muscles need merely a slight increase in activation to tense the spinal segments to provide stability during functional movements – thus, resist external loads and by that function, can decrease the load on the spinal segments (Stokes *et al*., 2011:800). Another muscle contributing to postural stability is the quadratus lumborum (QL) (Akuthota & Nadler, 2004:87). As stated by McGill (2001:28), the QL consists of longitudinal, inferior oblique and superior oblique fascicles. The superior oblique and longitudinal fibres assist with respiration by stabilizing the last rib and the inferior oblique fibres assist with side flexion of the lower back, thus playing a major role in stabilizing the spine through isometric contractions (Kibler *et al*., 2006:190).

Lastly, the diaphragm which forms the top of the core provides stability to the lumbar spine when it contracts by increasing IAP (Ebenbichler *et al.,* 2001:1891). All of the abovementioned structures play an integrated role in the core of the body when doing activities such as running, kicking or swimming. They provide distal mobility when using the extremities due to the stability originating from the most central part of the body (Kibler *et al*., 2006:190).

In conclusion, the core consists of various elements and serves as the central point for movement development. Even though the studies mentioned above state the role of core stability during movement of the body and extremities, few could draw a correlation to athletic performance (Tse *et al.,* 2005:552; Silfies *et al*., 2015:364).

2.2.2 Local and global stabilization system

Bergmark classified the different trunk muscles into two groups: the local stabilization system (LSS) and the global stabilization system (GSS), similarly, Liemohn *et al*. (2005:583) stated that athletic activities involve continual integration of these systems. In terms of the lumbo-pelvic-hip-complex, active stability can be divided into local and global muscle-systems according to muscle fibre dominance, anatomical location, structure, biomechanical potential and consistent and characteristic changes in the presence of dysfunction (Comerford & Mottram, 2001:22; Brukner & Khan, 2012:211).

The LSS is comprised of muscles that directly attach to the lumbar vertebra of the spinal column. As a result, it plays a role in controlling optimal positioning of the spinal segments and is restricted in torque generation (Warren *et al*., 2014:29). This system comprises the *intertransversarii mediales, interspinales* and the *rotatores* (Borghuis *et al*., 2008:898). These muscles do not fatigue easily and are able to keep the spine in a neutral position due to their short momentum arms and high-density muscle spindles (Liemohn *et al*., 2005:583). For the reasons stated above, the LSS is seen as very important in core stability due to its coordinating function during movement, preventing abnormal biomechanics that can cause injury (Warren *et al*., 2014:29).

The GSS consists of muscles that attach to the thorax and the hips (Borghuis *et al*., 2008:898; Hibbs *et al.,* 2008:997). This system is made up of the RA, longissimus thoracis and the EO (Warren *et al*., 2014:29). These muscles can create torque and are able to resist bigger external forces than the LSS due to their large momentum arms thus keeping the body in a stable position (Warren *et al*., 2014:29). McGill *et al.* (2001:27) established that the spine - with its surrounding passive structures - can only hold 90 Newton of compressive force; this highlights the importance of the core muscles to support the spine. Thus, without supporting core muscles assisting with grasping the body in a stable position, the spine will give way when twenty pounds of pressure is applied to it. However, for the core to maintain stability without increasing rigidity, it needs to provide tension at the spinal segments (Kibler *et al*., 2006:190). When training the core, the centre of attention should be to attain the optimal balance between mobility and stability (Frederickson & Moore, 2005:675).

2.2.3 Local stabilizers, global mobilisers and global stabilizers

Furthermore, not only are muscles classified in different groups, Comerford and Mottram, (2001:16) also classified the function of the muscles into three different groups, namely: the local stabilizers (LS), the global mobilizers (GM) and the global stabilizers (GS). The LS maintain postural control through a wide ROM and eccentrically resist momentum (Borghuis *et al.*, 2008:898).

The GM, on the other hand, are load transfer muscles and concentrically produces movement during acceleration of body parts for sporting activities and they usually also cross a few segments. The GM perform a functional role in enhancing stability by stiffening the core via fascial attachments (Comerford & Mottram, 2001:16). These muscles are integral to core stability within their capacity to transfer torque and momentum during repetitive, high-load, integrated kinetic chain activities (Behm *et al.*, 2010:94).

According to literature, it has been proven that LS activates during asymmetric low load lifting tasks whereas the GS shows insufficient activation and contraction during these low loading tasks, thus supporting their mobilizing function (Borghuis *et al.*, 2008:898). The multifidus, IO, semispinalis cervicis and TrA are part of the LSS, whereas the RA, *longissimus thoracis* and the EO make up part of the GSS (Comerford & Mottram, 2001:16). Therefore, for optimal stability, a strong LSS and GSS are both needed to function within a collected manner in order to optimize movement and to reduce the risk of injury (Warren *et al.*, 2014:29). The LSS and GSS are also supported by the passive structures (Kibler *et al.,* 2006:190). Not only are the muscles around the lumbar spine responsible for movement, but the coordination of all these surrounding muscles also provides stability.

The provided stability creates a neutral zone that is defined as a small range of intervertebral motion near the joint's neutral position where minimal resistance is offered by the osteoligamentous structures (Akuthota & Nadler, 2004:86; Kibler *et al.*, 2006:190; Slosberg, 2010:3). Therefore, disruption or damage to any of these passive osteoligamentous structures that is made up of the zygapophyseal joints, lamina, pars interarticularis and the pedicle, results in uncontrolled movement (Akuthota & Nadler, 2004:86). Panjabi (1992(b):392), also found that the size of the neutral zone can increase with various situations such as: degeneration of cartilage, ligament ruptures or weakness of the stabilizing muscles, thus leading to functional instability.

2.3 CORE FUNCTIONAL MECHANISMS- REGULATION OF INTRA-ABDOMINAL PRESSURE CHANGES THROUGH THE CORE

Arjmand and Shirazi-Adl (2006:1266), describe the additional functions of the core, which include: a breathing mechanism related to the generation of IAP, postural control mechanisms including co-activation between axial flexor and extensor muscle systems and postural-movement control of the proximal girdles. The three abovementioned systems are interdependent and should function in coordination with each other to deliver adjustable and multipart patterns of control when working in combination with the co-activation of the different muscles involved (Key, 2013:541). The muscles that assist with IAP are the lumbar multifidus, the interspinales, psoas muscles, medial fibres of QL, the IO muscles, intertransversarii, the pelvic floor muscles (PFM), the diaphragm and the TrA (Ebenbichler *et al*., 2001:1890; Sharrock *et al*., 2011:65).

There are several functions that require proper IAP by properly modulating the volume and the pressure of the thoraco-abdomino-pelvic cavity in order to unload the spine (Arjmand & Shirazi-Adl, 2006:1265).

To only name a few, sneezing, coughing, vomiting, birthing, functional expiratory patterns as well as impact activities such as jumping and running all require proper IAP to distribute the load of activity in order to complete the action and prevent the risk of injury to the vertebral spine (Griller *et al*., 1978:275). One of the main muscles responsible for creating pressure change mechanisms is the diaphragm, whereas IAP is still considered the key to function properly - which is achieved through the proportional activity of the TrA, pelvic and thoracic diaphragms (Ebenbichler *et al*., 2001:1891).

2.3.1 Breathing and postural control as the root mechanisms of core control

George (2016:online) and Key (2013:546), highlight the fact that maintaining an upright posture reduces overcompensation of the spine and enables individuals to inhale and exhale deeply, aiding in the breathing process that plays a significant role in most aerobic sporting activities and thus is seen as a crucial component for optimal performance.

During normal breathing, the rib cage expands in a lateral fashion and can only occur if the diaphragm and thorax pushes out the ribs due to sufficient IAP (De Troyer, 1997:709). Breathing also slightly disturbs the trunk by changing its shape when inhaling or exhaling and is counter-resisted by the sensori-motor activity that occur during small displacements from the lower limbs and lower trunk boosting the reflex mechanism, ensuring proper postural control (Hodges, 2002:299). Therefore, IAP generated by the breathing process helps with postural support and also assists the stabilization system (Cholewicki *et al.*, 1999:13).

2.3.2 Core control and the intra-abdominal mechanism

Lederman (2010:85) emphasized the necessity of core stability as a component of neutral spine positioning and IAP due to its stabilizing or coordinating function to ensure proper posture, preventing biomechanical injuries. Additionally as mentioned, the lumbar spine is one of the most important structures resisting dynamic forces and assisting the completion of athletic activities that are assisted by the IAP that creates a co-activation of muscles of the pelvic floor and the TrA (Ebenbichler *et al.*, 2001:1890). This natural response provides support to the spine, pelvis and tenses the thoracolumbar fascia in order to accomplish the movement or task (Hodges *et al.*, 2001:999). As confirmed by Cholewicki *et al.* (2002:127), trunk muscle co-activation is proportional to IAP being generated. Thus, it is important that IAP is at a suitable level when completing an action to assist the movement through postural support and also to ensure optimal breathing during activities without damaging any of the surrounding structures (Kolar *et al.*, 2012: 358).

2.3.3 The principal elements contributing to core control

2.3.3.1 *The diaphragm*

The diaphragm is one of the main muscles responsible for respiration, but as stated by Kolar *et al.* (2010:1064), it also plays a vital role in controlling posture when assisting in the development of IAP. The diaphragm is partially responsible for creating IAP in order to create postural control before movements of the limbs occur by simultaneously contracting with other muscles such as the PFM and the TrA (Ebenbichler *et al.*, 2001:1891; Kolar *et al.*, 2010:1064). The diaphragm reacts differently to respiratory demands than to postural demands due to its uneven recruitment pattern during contraction.

In a study compiled by Key (2013:545), the researcher found that the descent of the diaphragm in reaction to limbs' movements are much greater compared to tidal breathing without any movement and although the function of the diaphragm is mostly reflexive, it can also contract voluntarily free from respiration. Lumbar stiffness is therefore directly influenced by the diaphragm due to the posterior part that attaches between the twelve thoracic vertebrae and the third lumbar vertebra (Richardson *et al.*, 2004:187). When the diaphragm is activated and there is no synchronized activation of the lumbar extensors or abdominal muscles - an extensor twisting force develops in the spine (Hodges *et al.,* 2001:1004). As found by Hodges *et al.* (2001:1003), when a need for oxygen exists (during exercise; asthma; or hypercapnoea), the first priority is respiration in order to meet the oxygen demand and as a result it leads to reduced activity of the diaphragm, the TrA and the PFM - which leads to insufficient IAP due to inadequate postural control. When the spine is overloaded and an increased ventilator demand occurs, the big axial muscles stabilize the trunk because the diaphragm automatically switches over to breathing mode and this, in some cases, entrain the abdominals to respiration (McGill *et al.*, 1995:1772).

2.3.3.2 *The abdominal muscles*

The abdominal muscles are comprised of a set of myofascial sheets that form a wall around the pelvic area and work in controlled collaboration to assist postural movement control as well as respiration (Key, 2013:545). This wall is known as the anterolateral abdominal wall (ALAW). The muscles of the ALAW should be conditioned to support functional ability, but should be done in such a manner that it does not damage the spine (Akuthota *et al.,* 2008:41). Hodges and Richardson (1999:1005), found that all the abdominal muscles do not contract instantaneously. The deeper abdominal muscle TrA activates first, followed by activation of the superficial muscles, RA and the obliques.

During breathing and postural control, the TrA, more than the superficial abdominals, is also mainly involved in producing IAP independent of the direction of the movement (Eriksson *et al.,* 2011:476). The RA and obliques on the other hand are more involved in controlling the rotational forces in relationship with the spine, pelvis and thorax during postural movements and can be seen as task dependent muscles (McCook *et al.*, 2009:759). These task dependant muscles work through low-grade daily activities, but also support the body during activities that highly load the body by limiting breathing and also stiffening to produce stability (Ebenbichler *et al.*, 2001:1891).

It is important to understand that the TrA does not work in isolation but is the first to contract to ensure optimal IAP and provide stability to the body (Ebenbichler *et al.*, 2001:1890). Cresswell *et al.* (1992:409) concluded that changes in IAP is mostly related to

TrA activity even though some researchers rather believe it is the diaphragm (Hemborg *et al.,* 1985:25).

It is very important to distinguish between these muscles and their function in order to train the athlete to improve performance. When conditioning occurs where the main focus is to improve stability and control, it is important to focus on specific activation of the stabilizers and not necessarily only focusing on strengthening of the abdominals (Key, 2013:545). The main purpose for muscle activity is different for pelvis movement than for thoracic movement: when the pelvis recruits the movement, the internal oblique is mostly active, whereas during a straight leg raise (SLR), there is more activation of the lower IO and less of the EO, although some studies also state the recruitment of the TrA (Beales *et al.*, 2009(b):1; Vera-Garcia *et al.*, 2011:902). Urquhart *et al.* (2005:298) found that the inferior and middle regions activated independently of the superior region and stated that the biggest postural activation reflexed in the inferior region: the lowest activation in the superior region and the part in between is mostly connected to breathing.

The TrA plays an important role during breathing by assisting optimal diaphragm activity by providing stability to the rib cage to assist diaphragm activity but also counter-assist the abdominals and as a result, assists the creation of optimal IAP (Key, 2013:546). During inspiration and expiration, the abdominals play an important role in assisting the diaphragm - thus the higher the oxygen demand the quicker the respiratory process and the more involvement of the abdominals are noted with the TrA activating first (Beales *et al.,* 2010:313). The abdominal corset is activated by a maneuver called the Abdominal Drawing in Maneuver (ADIM). The purpose of this maneuver is to activate TrA without or with minimum contraction of the abdominal obliques to ensure a neutral spine while pulling in their abdomen (Richardson *et al.*, 2004:185). Numerous scientists also found that when the ADIM is accomplished and performed correctly, the PFM and the diaphragm is also recruited (Allison *et al.*, 1998:98; Sapsford & Hodges, 2001:1087).

O'Sullivan *et al.* (1997:2959), also reported positive outcomes in patients with back pain when lumbar multifidus activation was combined with the ADIM. Individuals often struggle to master this ADIM correctly (Beith *et al.*, 2001:86). Ishida *et al.* (2012:427), also reported much higher initial activity of the internal oblique and TrA during maximal exhalation than performing the ADIM. Grenier and McGill (2007:59), also found that the outcome of utilizing a stability belt around the pelvis to assist the abdominal wall is a much more effective way to increase pelvic stability and lumbar stiffness than the ADIM, but should not jeopardise the normal movement of the spine by giving too much rigidity.

The thorax and pelvis lose their control and can only partially assist the diaphragm in generating IAP when the ALAW does not activate properly since it has been noted that it bulges the abdomen, causing a disruption in neutral spine positioning (Ebenbichler *et al.,* 2001:1890). On the other hand, neutral spine positioning can also be lost when the abdominals are overactive because it inhibits diaphragm descent due to the thoracic opening being constricted and by that - obstructs the response and coordination between the pelvic floor, TrA and the diaphragm - resulting in insufficient IAP generation (Padoa & Rosenbaum, 2016:94)**.** Therefore, to ensure neutral spine positioning, all the muscles should be balanced in order to create optimal IAP to stabilize the spine.

2.3.3.3 *The pelvic floor*

The PFM need to activate when IAP is elevated to assist with the increased pressure (Sapsford & Hodges, 2001:1081). As stated by Junginger *et al.* (2010:73), in order to avoid bladder neck depression, the PFM's activation should be higher than IAP tosecure stability and help with the regulation of breathing patterns – more activation was observed during expiration (Hodges *et al.,* 2007:366). Sapsford *et al*. (2006:221) also reported higher activation of the PFM in individuals sitting in an erect position on an object without support than individuals with a slummed sitting posture. Furthermore, Capson *et al.* (2011:169) reported higher resting PFM activation in standing individuals, which indicates how different postures influence PFM activity and reported it as much higher in individuals with a hypo-lordotic posture. Contraction of the PFM assists the abdominals in contracting and also in intrapelvic-myomechanics to ensure pelvic control (Sapsford & Hodges, 2001:1086; Key, 2010:300).

2.3.3.4 *The paraspinals*

The ES, intertransversi, rotatores and multifidus are local muscles assisting lumbar extension (Akuthota & Nadler, 2004:87). The longissimimus and iliocostalis are the two muscles forming the lumbar ES and act on the back through tendons that link to the pelvis (Van Putte *et al*., 2017:333). These muscles are supreme in extending the lumbar spine due to their long moment arms and also create posterior shear when flexing the lumbar spine (Ebenbichler *et al*., 2001:1891). Thus, they provide trunk stability and assist with balancing external loads by unloading the spine (Borghuis *et al.*, 2008:899). The rotators and intertransversari have small momentum arms and ly deep and medially to the ES (Ebenbichler *et al.*, 2001:1890). The abovementioned muscles (rotators and intertransversari) are responsible for vertebral positioning, due to their high muscle spindle configuration and protect the ligaments, discs and the articular structures from injury. The multifidus, on the other hand, crosses more than two levels of the spine and are mainly responsible for segmental stability due to their short lever arms (Van Putte *et al.*, 2017:333).

2.4 CORE CONTROL

Hodges (2003:362), declared that control of the core consists of coordination rather than strength. The contraction of the core is the result of specific co-contraction of various muscles in a specific coordinated manner in order to develop compound control patterns as well as optimal movement (Hodges, 2003:362). Key (2013:547), previously explored the activity of the core and found that it relies on the feedback of the sensory system. Muscles work together to provide stability and cannot activate on its own (McGill, 2009:16). To train individuals to control their core includes teaching those plain motor abilities (Akuthota *et al.,* 2008:41). Ebenbichler *et al.* (2001:1890), further elaborated that for individuals to be able to control the body during functional movement, one should be able to activate the trunk muscles by synchronizing their postural and respiratory roles, which can easily be achieved through good synchronized IAP. Core control can be defined as the athlete's capability to produce ideal IAP to maintain respiration as well as to provide stability to the torso by controlling the posture during static and dynamic movements (Key, 2013:547). The slightest changes in the design of motor activity can cause dysfunction of the core due to the deep muscles activating too late - causing overactive superficial muscles to take over their function (Hodges, 2003:366). Over-activity of the superficial muscles can increase trunk stiffness resulting in restricted spine movement which can further result in chronic lower back pain (CLBP) (Mok *et al.*, 2007:537). To conclude; the biggest challenge is fair synchronization and endurance of the involved muscles, rather than poor muscle strength.

Research also showed that CLBP is the result of the deep muscles (TrA, lumbar multifidus and transversus multifidus) either activating too late or reduced activation during movement noted altering proper IAP and stability (Hodges & Richardson, 1997:368; Ferreira *et al.,* 2004:2560).

Along with improper IAP, it has been recorded that the role of the diaphragm is also disturbed (Key, 2013:548). As found by O'Sullivan *et al.* (2002:1), individuals who completed an active straight leg raise (ASLR) where the side that experienced pain alternately caused patients to brace their obliques and chest muscles while splinting their diaphragm, causing the PFM descent to increase. Along with the abovementioned, the starting position of the IAP had moved, breathing increased and breathing patterns started to vary (Beales *et al.*, 2009(a):867). Thus, the diaphragm should not only be able to move to assist the PFM, but also assist in the generation of IAP (Kolar *et al.*, 2012:358)

2.4.1 How to identify risks or problems with the core

As described Key (2013:548), NMC of the core sometimes get avoided causing various alterations, namely: a change in the sagittal position of the pelvis; a change in the alignment of the spine; and lastly, trying to create stability to certain segments by relying on extrinsic control patterns to provide a stable spine even though there is not sufficient intrinsic segmental control. Thus, it can be summarized that the IAP mechanism gets disturbed when there is altered diaphragm function and the more the form of the body changes, the bigger the alteration - which evidently inhibiting proper respiratory and postural control that can hinder the spine or pelvis (Frank *et al.*, 2013:64) (Figure 2.2).

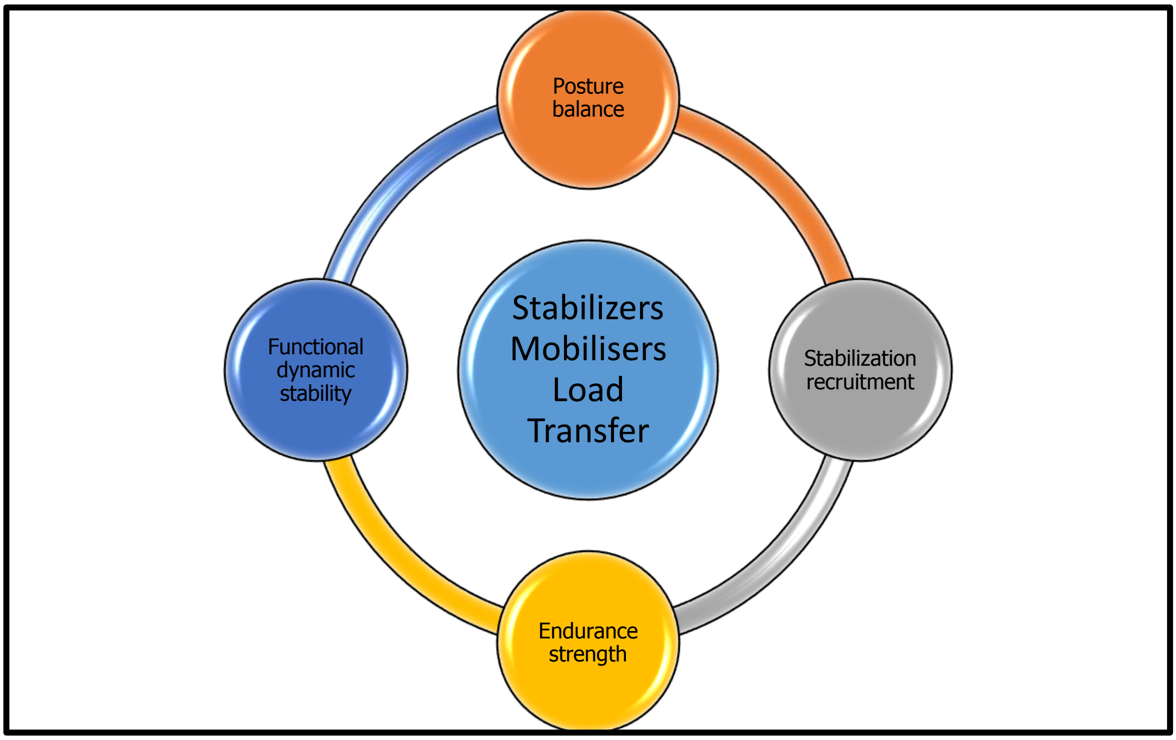

Figure 2.2: Functional core stabilization system (Bliven & Anderson, 2013:516)

Another way to identify possible risk factors of the core is by looking at the changes in the architecture of the core. For example, pelvic crossed syndrome is described as a syndrome caused by changed postural alignment or altered activation patterns of the regional fascia (Liebenson, 2007:205). One of the easiest ways to summarize individuals' problems is by observing the way they sit or stand (Schmidt, 2016:online). The subjective orientation of the ALAW and the thorax is a good indication of the activation and equilibrium of the TrA and the diaphragm. When the TrA is under-active, the shallow muscles like the obliques and RA will mostly take over (Key, 2013:548).

2.5 MEASURING CORE STABILITY

Due to a lack of consistency in measuring core stability, it is difficult for coaches to determine the essence of individualised core strengthening programmes (Akuthota *et al.,* 2008:40). Most researchers use different methods to determine core stability and for this reason no recorded standard has yet been established (Kibler *et al.*, 2006:194). Many tests also simply measure individual aspects of stability (Bliven & Anderson, 2013:516). This might be the reason for clinically dividing and organizing muscles into different groups (Bliven & Anderson, 2013:515).

Most athletic activities include a running component that requires a multi-plane, task-orientated test to determine the strength of the core since functional stability is required through subsystems working together to provide stability in certain positions.

As suggested by Noehren *et al*. (2014:1308), the trunk stability test (TST) is a scientifically proven test to measure core NMC with an intra-class correlation coefficient (ICC) = 0.93. In contrast, Butowicz *et al*. (2016:21) and Okubo *et al*. (2010:749), believe that the elbow toe test is a sufficient test to determine core NMC, for it evaluates the control of the whole lumbar complex when performing the test unilaterally and also showed good voluntary muscle contraction of 42% ±20% for the right TrA and 51% ±28% for the left TrA.

Another medical test that has been clinically proven to test the NMC of the trunk on unstable surfaces is the Y-balance test (YBT) (Fullam, 2014:34; De la Motte *et al.*, 2015:358). Plisky *et al.* (2006:915), also reported that the YBT is a sufficient test that can assist with the prediction of limb injuries identified in athletes.

Even though it is believed that frail core stability can contribute to muskoskeletal injuries and while the existence of a variety of tests are available to test that, most of the tests are not clinically proven to measure the stability of the core.

Kibler *et al.* (2006:195), also suggested assessment in three-plane standing positions. Even though valid in construct and functionally applicable to this study, these qualitative ratings are still only reliant on an examiner's credibility and experience and cannot yield the reliable objective criteria required for use in profiling of athletes competing in different sport codes. Furthermore, there is the prerequisite of the tonic motor recruitment of local stabilizers prior to initiation of a movement that requires differentiation of the local and the global muscle systems.

Akuthota *et al.* (2008:41), furthermore suggested a variety of tests to determine the ability of the overall core in combination as well as isolating the specific muscles, for it is assumed that a strong core does not only involve trunk strength. These suggested evaluations include the endurance trunk stability test (ETST); the prone extension endurance test (PEET); and the side flexion endurance test (SFET). A study done by Allah and Nagi, (2013:online) used the ETST, PEET and SFET to determine the correlation between core stability and athletic performance. The ETST reported mean values of 206.9sec ±92.1sec (pre), 215.5sec ±62.7sec (post) and 164.5sec ±7.2sec (pre), 176.2sec ±48.9sec (post) with no significant differences ($p>0.05$) for the core and controlled group respectively.

The results also reflected mean values for the ETST, PEET, right flexion and left flexion of 130.36sec ±9.05sec 165.17sec ±2.78sec, 103.2sec ±2.38sec and 99.6sec ±1.96sec for male university athletes respectively. Furthermore, a positive correlation existed between core stability, the chest throw ($r=0.57$) and the T-test ($r=0.90$), but no significant correlation to the forty-meter sprint ($r=-0.14$) and a negative correlation to the vertical jump ($r =-0.07$). Therefore, we can summarize that even though core endurance improves, it does not necessarily improve athletic performance.

Another study done Nesser and Lee (2009:23), also used the ETST with an ICC = 0.98, the PEET with an ICC = 0.93 and the right and left flexion test with an ICC = 0.93 to determine the athlete's core stability. The values reported for the trunk flexion, back extension, right flexion and left flexion was 216sec ±83.4sec, 182sec ±70.4sec, 128.7sec ±56.8sec and 122.7sec ±36.2sec for division one female athletes respectively. Nevertheless, the study reported no significant correlation between core stability and various performance parameters such as the forty-meter sprint (r =-0.37), the vertical jump (r =-0.28) and the squat (r =-0.14). On the other hand, even though this study did not use the squat as one of the performance measures for athletic ability as the previous study mentioned, it can still be concluded that core stability does not directly relate to sport performance enhancement. Although studies focus more on core endurance than core strength, Sharrock *et al*. (2011:66) believed that core strength is critical for athletic performance (Tse *et al*, 2005:547; Allah & Nagi, 2013:5). Core performance is not only measured by endurance of the muscles of the trunk, but should include coordination, muscle recruitment, strength and optimal control of all active and passive structures involved (Warren *et al*., 2014:31). The double leg lowering test (DLLT) with a blood pressure cuff (BPC) feedback is another modality used to measure core musculature and has been found to be an appropriate measure of core stability because it measures the strength of the abdominals, needed for most sport activities (Sharrock *et al*., 2011:70).

This method measures the pressure changes as the stabilization system tries to stabilize the trunk when lowering the legs. As stated by Sharrock *et al*. (2011:67), the DLLT test requires great levels of core activation to assist the trunk when lowering the legs because of the small base of support (BOS) and long lever arm and it also consists of excellent intra-tester reliability. Athletic movements also require simultaneous synchronized muscle contraction. For this reason, this study used the DLLT to determine the core strength of the athletes. When performing the DLLT, the pressure changes when the unit transduces pressure from three air-filled chambers to a sphygmomanometer gauge due to limb movements. Any change more than 10mmHg above or below the baseline represents inability to control the trunk. As Azevedo *et al*. (2013:34) cited from a study, the accuracy of the unit has been identified as ±3mmHg.

Krause *et al*. (2005:1345) also mentioned as cited from a study, that the ICC for repeated measures of the DLLT was 0.98, with a significant difference between men and women ($p<0.001$). The mean degree of core strength by means of a DLLT for university male and female athletes was found to be 47°and 55° respectively. Sharrock *et al.* (2011:70), also reported no significant correlation between the DLLT and various sport-specific performance measures such as the T-test (r=0.05), forty-meter sprint (r=0.14) and vertical jump (r=-0.17). Furthermore, Anderson *et al*. (2014:17), also tested core musculature by means of a DLLT and found a mean degree of core stability for males and females to be 15° and 37° respectively. The mean degrees of core stability for healthy populations as found by Krause *et al.* (2005:1345), were 15° ±2.3° and 37° ±3.4° for men and women respectively.

Even so, another question raised is, the accuracy of some core stability measures as electromyogram (EMG) data mostly test muscles in isolation, making it difficult to determine these muscles' strength during functional movements or to quantify the findings (Kibler *et al.,* 2006:194). Nonetheless, literature does not provide subsequent evidence as to whether core stability relates to functional performance or not. For this reason, this study was performed to provide evidence concerning the relationship between core stability and athletic performance and to fill the gaps in current literature to help formulate appropriate methodologies.

2.6 CORE STABILITY TRAINING

There are many conflicting studies in the literature regarding core stability training (Hibbs *et al*., 2008:999). While some trainers believe that the abdominals and RA are trained during flexion of the spine, others focus on the stabilizing function of these muscles, highlighting the fact that these muscles actually stiffen during movement to provide stability rather than generating flexion (Callaghan *et al.,* 1998:8). Equally important, Tampier *et al*. (2007:2872) also indicated recurrent flexion and extension of the vertebra two of the major mechanisms of injury. Furthermore, some trainers instruct their athletes to pull their naval to their spine to improve stability, which is probably incorrect because this movement does not engage the most important stabilizers of the spinal column as it is found that the muscles playing the biggest role in providing stability are highly task specific (McGill, 2010:33).

Some examples that have been identified include that the QL is considered an important structure in stability, yet it has been neglected by many (Kavcic *et al*., 2004:1261); pulling the abdominals to the spine decreases stability (Kavcic *et al*., 2004:1254; Potvin & Brown, 2005:973); and lastly, literature shows that there is insufficient TrA activation in several individuals that suffer from back injuries although these disorders can be present in other muscles involved as well (Cholewicki *et al.,* 2002:568; Silfies *et al.,* 2009:1159).

The moment that individuals exert tasks of increased demand, they tend to struggle to activate TrA in isolation due to the fact that they are too weak and that IO assist the TrA during high demanding tasks (McGill, 2010:33). Most trainers use the motor re-education approach to condition the core and strongly focus on the IO, TrA, multifidus and the PFM (Sapsford, 2004:9). The latter statement relates to various studies done on core stability and the altered load transfer effect due to NMC deficits (Hungerford *et al*., 2003:1593; Bliven & Anderson, 2013:516). The physiological benefit of core exercises can be viewed as the increased sensitivity of muscle spindles within the active subsystems. Therefore, the greater the readiness of the kinetic chain to absorb external load, the smaller the risk of injury (Kenney *et al.*, 2012:220).

To optimize core conditioning, the strengthening of these muscles should take place in three phases: Training the motor skills of type one slow motor units within the active stability system (Akuthota *et al.*, 2008:41). This phase of training is very important as a deficit in core stability has been identified in plentiful cases to be due to loss of NMC, rather than a strength deficit (Ebenbichler *et al.*, 2001:1892). Pain and injury, on the other hand, can also restrict the feed forward properties of tonic muscles, but can be corrected with exercise (Comerford & Mottram, 2001:23). Therefore, the timing, amplitude and endurance are crucial when recruiting these tonic muscles (Akuthota *et al.*, 2008:41).

The endurance modality of high repetition sets as well as balance exercises are recommended, since both modalities have been found to increase spinal stability (Frederickson & Moore, 2005:682). To further improve performance and to enhance stability, optimal load transfer training through strengthening exercises should evolve targeting the global mobility system (Frederickson & Moore, 2005:680). Finally, progression should comprise functional movements and sport-specific drills (Figure 2.3) (Behm *et al.*, 2010:96).

During all stages of conditioning it is important to ensure activation of the tonic muscles before movement can take place and also to ensure proper IAP by incorporating sufficient diaphragmatic breathing that enhances PFM activity (Sapsford, 2004:7). Sufficient tonic activity could produce optimum placing and postural awareness as steady base for movement. Muscle recruitment imbalances may lead to biomechanical dysfunction and injury if training of the athlete does not include timely progression of the abovementioned stages (Comerford & Mottram, 2001:9).

Further literature reflects on the ability of the core to empower the rest of the body even more than when it is not working correctly (McGilll, 2010:34). As found by Sharrock *et al.* (2011:65), the core supported the movement of the hips when there was insufficient hip strength to complete the required action.

From the results found by a study compiled by Santana *et al.* (2007:1271), it was concluded that individuals were able to bench press more weight while lying down than standing up, which indicates the lack of core strength in the standing position. Thus, it can be summarized that the core - more often than not - restricts rather than produces movement. Therefore, movement during high load sport events should be created from the hips and is only possible when the core is activated and strong (Sharrock *et al.*, 2011:65). Equally important, Akuthota *et al.* (2008:43) also stated that when there are insufficient biomechanics during these sporting events lumbar injuries can occur (Ebenbichler *et al.*, 2001:1892). For this reason, it is important for trainers to not only focus on load and intensity, but also to correct the athlete's biomechanics.

2.6.1 Causes of back disorders

During training, most trainers do not focus on correcting faulty posture that can possibly lead to injury and pain (Schmidt, 2016:online). Thus, in order to improve load or to adjust a program in order to improve performance, it is essential to eliminate the factor causing the pain (Brukner & Khan, 2012:216). To give an example: when the back is too rigid and cannot tolerate flexion, individuals try to ease the pain by pulling up their knees, causing more harm due to the deep tissue damage (Snook, 1998:14). Another example is an individual with a slouched posture, causing the involved muscles to be stiffened the whole time until it results in pain (Jongbloed, 2017:online). Instead of relaxing the muscle by correcting posture to de-load the spine muscles, some medical professionals prescribe anti-inflammatories rather than addressing the problem causing the discomfort (McGill, 2007:157).

2.6.2 The science of the core

In order to optimally train the core, it is of utmost importance to understand stability in totality (Brukner & Khan, 2012:215). As stated by McGill (2010:36), maintaining balance on a stability ball does not address all the muscles necessary for spine stability, but merely enables one to balance and compress the spine even more when done incorrectly. In contrast, exercises including a body-blade, engage the whole core - thus advancing stability (Moreside *et al.*, 2007:153).

2.6.3 Tolerance and capacity

Athletes who strive to improve their performance should carefully consider the choice of the exercises they want to perform (Baechle & Earle, 2008:386). It is very important that the exercises do not exceed the athlete's ability to tolerate the load and cause injury or damage to the involved structures (McGill, 2010:36).

Furthermore, it is also important to ensure the individual has the capacity to complete a certain number of exercises without pushing to do more than what the individual is able to endure. Therefore, to ensure the awareness of what the client's capacity is at that stage, it is crucial to implement a thorough subjective and objective evaluation that includes the individual's static and dynamic posture, ROM, flexibility, strength, endurance, explosive power, speed and agility as well as a thorough background of the individual's history (Frederickson & Moore, 2005:675). It is equally important for trainers to correct static and dynamic abnormalities to prevent back pain or injury to any structures of the body. An example of this statement is to educate individuals to bend their knees when picking up a box or load from the floor or stand in an upright position rather than slouch (Arjmand & Shirazi, 2006:1269)

The different phases of exercise described by Akuthota *et al.* (2008:41) can serve as guidelines to reduce or even prevent the risk of injury. The first phase is described in terms of where all exercise modification and posture correction take place. The second phase focuses on integrating motor control into movement patterns to ensure optimal biomechanics. Phase three builds stability through the core and provides mobility in the joints to ensure that the body can function within a neutral zone where it is safe for movement to occur without the risk of incurring injuries. The next phase emphasizes endurance training. Phase five incorporates strengthening of the muscles to ensure that the body can resist external loads and the last phase emphasizes speed and agility (Frederickson & Moore, 2005:679-688).

As previously stated, athletes exercise and train to be better, faster and to optimize their performance (Tse *et al.*, 2005:547). Thus, to ensure athletes of better performance without getting injured before they do, it is important that trainers progress their training specific to the individual by progressing from optimal motor control during stabilizing activities until the athlete can maintain this correct motor control during higher load activities that include speed, agility, power, endurance and strength exercises. (Akuthota *et al.*, 2008:41).

To summarize, the core is not the main driver that produces movement, but is rather responsible for stiffening the abdominal wall to enable the rest of the limbs to generate force (Tse *et al.*, 2005:547). The core therefore needs to be strong in order to enhance the conditioning of the rest of the body and eventually fulfill athletes' goals of optimal performance within their sport code (McGill, 2010:44).

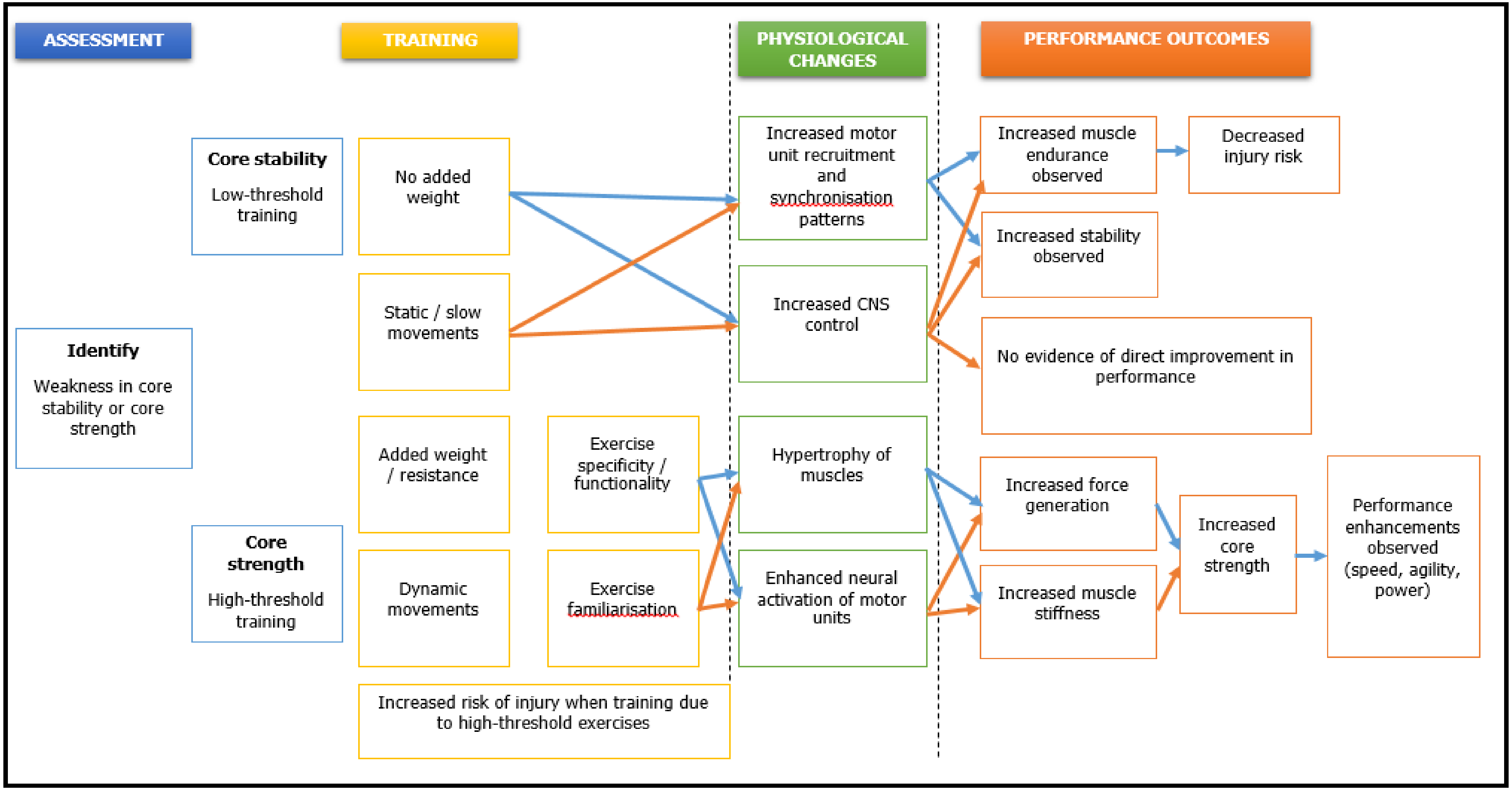

Figure 2.3: Core training and potential performance benefits: Summary of the principles of low- and high-load training with subsequent effects on core stability and core strength and the possible impact on performance as a result of scientific research carried out

2.7 STABILITY VERSUS MOBILITY

Akuthota *et al.* (2004:87) state that numerous muscles are involved in the core complex, which has also been confirmed by various other researchers (Kibler *et al.*, 2006:190; Hibbs *et al.*, 2008:998). The activation of these muscles results from the integration between multi-joint and single joint muscles (Borghuis *et al.,* 2008:899). Depending on the location and the size of these muscles, they have certain roles (Kibler *et al.*, 2006:190). The muscles with the bigger moment arms crossing several spinal segments function as the prime movers by integrating numerous joints and are activated during movements with a specific torque direction, producing force (Nichols, 1994:5). The muscles with the smaller lever arms are muscles crossing only a single joint and are activated during length-dependent activation patterns (Nichols, 1994:4).

Thus, integration of the force-dependent and length-dependent muscle activation patterns are required to produce distal mobility during movements, especially in a multi-segmented structure like the spine (Kibler *et al.*, 2006:190).

The patterning of this proximal to distal force generation creates interactive lever arms that protect the distal joints (Borghuis *et al.,* 2008:899). The position and movement of bordering body segments develop interactive moments at different joints in the central body segments in order to be able to develop enough force at the distal joints, as well as to create the optimal position for bone placement to reduce the load placed on joints (Kibler *et al.*, 2006:190). As stated by Anderson and Behm (2005:43), much research has been compiled on static posture and how muscles are able to maintain good balance, whereas limited research reveals how they maintain dynamic equilibrium when external forces are applied. To be able to maintain proper posture while applying an external force is the platform for success in most sport codes (Ebenbichler *et al.*, 2001:1892; Borghuis *et al.*, 2008:899). It is equally important to be able to cope with movements on unstable surfaces or during unstable environments, where it is expected that there will be an increase in the co-contraction of the different activation patterns, causing a decrease in the force to be produced (Anderson & Behm, 2005:49). However, Ebenbichler *et al.* (2001:1891), also found that co-contraction is needed to decrease joint ROM in order to provide stability during limb movements and to perform these high maintenance tasks, injury free.

Therefore, for athletes to enhance performance, they should be able to enhance their mobility, along with sufficient stability to prevent injuries and optimize movement performance (Borghuis *et al.*, 2008:899).

2.8 ATHLETIC ABILITY

Athletic performance has been defined as the ability to carry out sport-specific procedures and skill-related routines by the athlete who is conditioned, skilled and trained in physical activity (Hoffer, 2012:online). Various physical and mental components play a role in athletic ability and contribute to excellent performance in sport. Aerobic fitness, for example, is an important factor contributing to sport performance in various sport codes, but is only one of the components among several others. To name merely a few factors, besides fitness, contributing to the athlete's success: body composition, aerobic endurance, muscular endurance, muscle strength, explosive power, speed, anaerobic capacity, flexibility, agility, balance and coordination, reaction time, skill and technique, hydration, genetics, lactate threshold, fuel provision, metabolic machinery, exercise economy, oxygen uptake, oxygen consumption, age and gender; psychological factors such as: motivation and self-confidence, coping with pressure, analytic and tactical ability; socio-cultural factors such as: the level of competition, the influence of individuals in a society, customs and sport players; then there are factors playing a less important role but is still important like: the opportunity to train, the knowledge and availability of a skilled coach, equipment supply, sufficient nutrition, a good support system and many more (Kravitz & Dalleck, 2002:online; Wood, 2010:online; Ipatenco, 2015:online; Willet, 2015:online).

As stated by Bali (2015:92), four factors affecting an athlete's performance are stress, anxiety, tension and aggression. This is why Psychologists train athletes in the following areas: maintaining control of their emotions even though there can be things altering their ability to perform, maintaining focus and concentration, belief in their own abilities and to work hard to achieve the goals they set for themselves (Bali, 2015:92). As one can see, core stability is one modality among various others contributing to an athlete's performance, but because the one complements the other, athletes still go the extra mile to ensure they address each component in order to be the best. For this reason, clearance should be reached about the influence of core stability on athletic performance. However, although some authors believe that the body needs mobility and stability in order to produce balanced and controlled movements when doing certain movements like kicking, swimming and running, in order to optimize sport related performance (Kibler *et al.*, 2006:189; Borghuis *et al.*, 2008:901), the available literature does not yet quantify, if core stability in fact does better performance (Sharrock *et al.*, 2011:67).

2.9 PROGRAMME DESIGN

To ensure that athletes gets stronger and faster in order to improve their performance, a professional trainer should set up an individualized programme after completing a thorough needs analysis of the specific sport involved, as well as all the required skills necessary for the sport (Baechle & Earle, 2008:382). Equally important is the status of each athlete in order to provide a sufficient program for each individual's specific needs (Haff & Triplett, 2016:441-442).

Secondly, the selection of exercises with regards to requirements of the sport is very important. There are various types of exercises to choose from; core exercises, assistance exercises, structural exercises, as well as power exercises. According to Fredericson and Moore (2005:670), specific adaptation to imposed demands (SAID) is one of the most important principles when setting up a programme; therefore, the closer the exercise to the athletic demand, the more effective the exercise is.

The third step in setting up a programme concerns the frequency of training, depending on the season of the sport, the training load of exercises, the status of the athlete, as well as the type of exercise performed (Tan, 1999:294; Bird *et al.*, 2005:846; Haff & Triplett, 2016:448).

The fourth step involves the order in which exercises will occur (Baechle & Earle, 2008:390). Power exercises, for example, will occur early in the programme, followed by core exercises and then assistance exercises.

The fifth step is the training load and amount of repetitions, depending on the training goal of the athlete (Bird *et al.*, 2005:843). For example, endurance training, hypertrophy, strength or power.

The sixth step in setting up a programme, is the volume, the total amount of weight lifted in a session or week and the final step playing an important role in setting up a programme, concerns rest periods (Tan, 1999:293; Bird *et al.*, 2005:846).

In conclusion it is possible to physically enhance the athlete's ability when choosing the correct sets, reps and training modalities.

2.9.1 Power

Literature highlights some of the most important components in most sporting events (power, speed and agility) and presents several tests to quantify such performances (Hibbs *et al.,* 2008:1004). Even though this study focuses on power, speed and agility, none of these modalities can be applied without a good base of strength. As stated by Baechle and Earle (2008:73), muscle strength is the ability to apply force on an exterior object, whereas power is the time it took to exert the force. As seen in the human body, this will be summarized as to how fast an athlete is able to contract specific muscles, in order to produce rapid movements and is measured in Watts (Sandler, 2005:3). Stone *et al*. (2002:88), further solidify the abovementioned statement and list two factors that are considered very important in most sport codes; namely, the rate of force development (ROFD) and power output. Various sports require either fast, rapid movements (hockey, tennis) or demand the athlete to exert big forces overcoming gravity to move their body mass (running, gymnastics) or even to move their own body weight plus the additional weight of the opponent (rugby, wrestling) and cannot be possible if the athlete is not strong enough (Suchomel *et al.,* 2016:1420). Therefore, as stated by Suchomel *et al*. (2016:1419), muscular strength is strongly related to the rate at which the athlete can develop force resulting in faster stronger movements.

All sport involves some degree of body acceleration; therefore, it can be true that better power ensure faster movements. In other words, the better the ability of the athlete to perform physically demanding tasks, the faster they will be able to produce the movement, thus optimizing performance during activities such as running, swimming or kicking (Macedonio & Dunford, 2009:11). However, besides strength, Abt *et al*. (2007:1300), tested the endurance of athletes and concluded that fatigue of involved muscles can cause altered biomechanics, leading to injury due to higher loads placed on specific joints and therefore argue that core endurance training can improve both biomechanics and performance.

This study used the vertical jump as a measure of vertical power due to the fact that power is seen as a primary factor in most sport codes (Suchome *et al.,* 2016:1420). The vertical jump has an ICC = 0.96 (Carlock *et al.*, 2004:534) and is seen as a great instrument to assess lower body ability.

Furthermore, the vertical jump is also reported a test re-test reliability of ICC = 0.99 that further supports the fact that it is a great measurement instrument to determine an athlete's power (Reiman & Manske, 2009:152). Furthermore, Baechle and Earle (2008:278), reported vertical heights of 65cm and 47cm for competitive university male and female athletes respectively. To improve vertical power, Haff and Triplett (2016:445), suggested structural power exercises such as power cleans, snatches, front squats and jerks.

The medicine ball chest throw, on the other hand, was used to determine upper body power with an ICC = 0.84 (Reiman & Manske, 2009:251). Both upper and lower body power are seen as two important components used in many sports (Sharrock *et al.,* 2011:67). Sell *et al.* (2015:156), reported chest throw values of 264.90cm ±69.27cm and 280.06cm ±49.38cm for competitive university male and female athletes respectively. The previously mentioned study used a 3kg medicine ball, whereas this study made use of a 5kg medicine ball.

2.9.2 Speed

Speed is expressed as how fast an individual can accelerate and complete a distance measured in seconds and is also seen as an important component of success in many sports (Reiman & Manske, 2009:191). Voluntary muscle contraction enables the body to do specific movements (Miro, 2017:online). The stronger the athlete, the stronger the muscle contraction, the better the sprinting performance (Suchomel *et al.,* 2016:1426). Speed can furthermore be divided into different types of speed, namely: reaction speed, displacement speed and movement speed (Miro, 2017:online). For an athlete to accelerate to a top speed will require fast twitch fibres to be developed in order to run faster. According to extant literature, we can contemplate that a stronger core provides more stability and creates a better base of support for forceful leg movement to occur, improving the speed of the athlete. Nonetheless, various studies reported different conclusions (Tse *et al.*, 2005:550; Sharrock *et al.*, 2011:70; Reed *et al.*, 2012:700).

This study used the forty-meter sprint to determine the speed of the athlete and as reported by Triplett (2017:online), have a test reliability of ICC = 0.89- 0.97. The mean values for university athletes for the forty-meter sprint is reported by Allah and Nagi (2013:online), as

6.11sec ±0.53sec. Steffen *et al*. (2007:599), also reported forty-meter sprint times of 5.97sec ±0.25sec and 5.93sec ±0.26sec for both an intervention and controlled group respectively.

As suggested, many modalities such as strength, speed endurance, explosive power, plyometrics and rhythmic exercises such as power cleans, plyometric ladders and squats can all contribute to improved speed (Baechle & Earle, 2008:474).

2.9.3 Agility

Lastly, agility is defined as the ability of an athlete to accurately and rapidly change direction with optimal biomechanics and control of the body (Sheppard & Young, 2005:2). During sport activities, agility and leg speed are two important components needed for optimal performance in various sport activities (Pauole *et al.,* 2000:443). The abovementioned activities require both leg and arm movement, which require joint and ligament stability as well as a stable base of support in order to optimally produce and transfer forces (Sharrock *et al*., 2011:64). Internationally, agility is summarized as collective coordinative ability that is comprised of various motor control tasks such as adaptive ability, balance, combinatory ability, differentiation, orientation, reactiveness and rhythm (Tittel, 1991:194; Baechle & Earle, 2008:469). As one can see, agility involves forward running, backward running and side running movements that require a great deal of coordination. Therefore, in order to maintain efficient and optimal biomechanics during athletic movements, several contributions are required from the shoulder, back and knee joints, to the transition of forces from the core to the extremities (Sharrock *et al*., 2011:65). As stated by Haugen *et al*. (2016:2), insufficient core stability can alter biomechanics, leading to injury. Nevertheless, scientists differ in their opinion as to whether core stability enhances athletic performance or not (Okada *et al*., 2011:257; Sharrock *et al*., 2011:68; Reed *et al*., 2012:700).

This study used the T-test to determine the athletes' agility and reported an ICC = 0.98 (Pauole *et al*., 200:443). According to Haff and Triplett (2016:311), the time in seconds for competitive university athletes to complete the T-test is 11.92sec ±0.52sec and 10.08sec ±0.46sec for female and male respectively. Reiman and Manske (2009:202), reported T-test values of 10sec and 10.8sec for competitive university male and female athletes respectively. Furthermore, Pauole *et al*. (2000:446), reported T-test values of 10.94sec

±0.6sec and 9.94sec ±0.5sec for competitive university female and male athletes respectively.

Baechle and Earle (2008:473-474), suggested that a comprehensive agility program should include the following components: strength, power, acceleration, deceleration, coordination, dynamic balance as well as dynamic flexibility. He also advised that various techniques play a critical role when executing certain exercises and listed that all play a valuable role in the proper technique of agility drills: visual focus, arm action, deceleration, recovery, movement economy, body alignment and biomechanics.

2.10 CORE STABILITY AND ATHLETIC PERFORMANCE

As stated earlier, various studies have been done to define the relationship between core stability and athletic performance; however, none could quantify the relationship between these two variables.

2.10.1 Core stability and power

To summarize various results, Tse *et al.* (2005:550), completed an eight-week core intervention programme with college rowers and compared the results with a controlled group. According to this study, there were no significant difference in performance between the two groups with pre- and post- test vertical jump values of 56cm ±6cm and 55cm ±6cm and 57cm ±4cm and 57cm ±5cm for the core and controlled group respectively. In the same study, the chest throw also reported no significant difference between the pre- and post- tests between the core and controlled group with values of 9.06sec ±1sec 40-meter (pre), 8.55m ±0.86m (post) and 9.04m ±1.23m (pre), 8.84m ±0.81m (post) respectively. In conclusion, athletes improved their core endurance but their athletic performance stayed the same. Furthermore, the abovementioned study also used a 2kg medicine ball whereas this study completed the chest throw with a 5kg medicine ball.

Another study done on college baseball, handball and volleyball athletes reported vertical jump performance values of 50.37cm ±3.79cm with a negative correlation between the vertical jump and core stability (r=-0.07). The same study reported chest throw values of 735.7cm ±28.94cm with a positive correlation to core stability (r=0.57) (Allah & Nagi, 2013:5-7). Furthermore, Sharrock *et al.* (2011:70), tested core stability by means of a DLLT with a mean degree of 55° and 47° for females and male athletes respectively. This study also reported no significant correlations or relationship between core stability and athletic performance of the vertical jump (r=0.17) (p=0.331). Furthermore, core stability negatively correlated to the chest throw (r=-0.39) but statistically significant (p=0.023). Sell *et al.* (2015:152), also reported a significant negative correlation between the DLLT and the chest throw (r=-0.39, p=0.023). As one can see, there is much controversy as to whether or not core stability relates to athletic performance.

2.10.2 Core stability and speed

As found by Sharrock *et al*. (2011:70), there is only a small insignificant correlation between core stability and the forty-meter sprint (r=0.14) (p=0.44). Allah and Nagi (2013:online), also found a small correlation between core stability and the forty-meter sprint (r=0.14).

The mean values for university athletes for the forty-meter sprint is reported by Allah and Nagi (2013:online), as 6.11sec ± 0.53sec.

Steffen *et al*. (2007:599), also reported forty-meter sprint times of 5.97sec ±0.25sec and 5.93sec ±0.26sec for both an intervention and controlled group respectively and also found no significant relationship between core stability training and athletic performance (p=0.53). Another study done by Tse *et al.* (2005:550), completed a core intervention of eight weeks and reported no significant relationship (p>0.05) between core stability and athletic performance and reported normative values for pre- and post-testing for both the controlled and experimental group. The values for the forty-meter sprint was 6.27sec ±0.34sec and 6.28sec ±0.23sec for the pre- and post-test of the core group respectively and 6.28sec ±0.39sec and 6.22sec ±0.22sec for the pre- and post-tests of the controlled group respectively. Therefore, one can conclude that core stability might not relate to athletic performance. Furthermore, Sharrock *et al*. (2011:70), also found no significant correlation between the forty-meter sprint and core stability (r=0.14) (p=0.438).

2.10.3 Core stability and agility

According to Haff and Triplett (2016:311), the time in seconds for competitive university athletes to complete the T-test is 11.92sec ±0.52sec and 10.08sec ±0.46sec for female and male respectively. Sharrock *et al*. (2011:70) reported very small correlations between the T-test and core stability (r=0.05).

We can conclude that sufficient control and movement of the trunk with regards to the pelvis when completing athletic activities or high load activities such as running is very important in order to transfer energy through the kinetic chain to produce forceful movements (Tong *et al.*, 2014:244). Nevertheless, as stated above, there are contrasting findings in literature with regards to the correlation between core stability and athletic performance.

The Table below (cf. Table 2.1) produces a summary of studies done and the results they found after completing different types of training regimes.

Table 2.1: A selection of research findings about core training and resultant benefits on core stability, core strength, muscular endurance and performance

Study	Result	Recorded Performance	Method of data collection	Subjects	Exercises used in program
Liemohn *et al*. (2005)	Improved stability	Out of balance time. All exercises should be done every day for 4 days in a row.	Stability platform	16 college students (7 women, 9 men) Healthy	Side Bridge, Forward Bridge, Planking, Bird dog
Vezina and Hubley-Kozey (2000:1370)	Improved Stability	Tests were repeated after 6 weeks. There was improvement in the results of the level 1 trunk stability test (TST).	Surface EMG (2 on the trunk muscles and 3 on the abdominals	24 men Healthy	Tilt of the pelvis, TST level 1, hollow the abdominal area
Urquhart and Hodges (2005:393)	Stability effects	Used an EMG to test muscle activity; the posture and single leg stance reflected an effect on the muscle activity of all the abdominal muscles. The muscles responded different to the abovementioned movements.	Intramuscular EMG (on the obliques and TrA as well as surface EMG on RA	30 varsity girls Untrained	Rapid shoulder flexion in a standing and sitting position. Unilateral
Cosio-Lima *et al.* (2003:721)	Muscle activity increased. Strength did not improve	Used EMG to test muscle activity and Cybex to test strength of the abdominals, the knee and the back; The group	Surface EMG on the RA and ES vs intramascular EMG on the TrA	>200 varsity sport athletes	5 weeks of Swiss ball training, sit-ups and back extensions

		that did Swiss ball training had an increased EMG of muscle activity but their strength remained the same.			
Nadler *et al*. (2002:9)	Strength improved and fever injuries occurred	Their strength improved and there were fever injuries observed although there was different response on injuries reported in females.	Force plate, dynamometer	140 track athletes and basketball players (60 males, 80 females)	Worked out programme to strengthen the core
Leetun *et al*. (2004:926)	Poor strength produced more injuries	The weakness in abduction of the hip as well as external rotation of the hip led to more injuries.	Video camera, dynamomete, EMG, Force	45 Varsity Rowers	Strength of hip abduction, activity of the abdominal muscles and endurance of the back doing back extensions
Tse *et al*. (2005:547)	Muscle endurance improve. Performance stayed the same	During a repeated sprint, 40 m sprint, medicine ball throw, 2000m ergo test and the vertical jump participants showed no difference in performance although their endurance did improve.	EMG	41 female varsity athletes (soccer, volleyball, basketball)	Do a programme that include trunk extensions and side flexion for 8 weeks
Stanton *et al*. (2004:522)	Stability improved. Performance stayed the same	The Sahrmann core stability test, VO2 max test, stature and running economy found better core stability but no significant improvement in performance.	Surface EMG ES, EO, RA	18 young male athletes	Do structured Swiss ball exercises for 6 weeks
Meyr *et al*. (2005:51)	Stability and strength improved and led to improved performance	Single leg hop and hold and long jump and hold test were used. After completing a training	Strength tests, speed tests, jump test, video	41 female college athletes	Follow a program that involve the following for 6 weeks: strengthening of the core,

		programme, the distance of the long jump and hold increased as well as improved stability and strength and better performance after completing the programme.			resistance training, balance training and plyometric exercises

(Hibbs *et al.,* 2008:1003)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the study design in order to objectively evaluate the relationship between core stability and athletic performance measures in male and female university athletes. A detailed outline is given of the specific population included in the study and the eligibility criteria for both the male and female athletes.

In preparation for this study, literature was collected from electronic databases such as Kovsiekat, Pubmed, EbscoHost, ScienceDirect, as well as relevant academic journals and textbooks to inform methodological considerations. A specific method was used to gather data and the description of the collection process has been described as the research methodology. Creswell and Plano Clark (2007:4), explicate the research method as the complete process to conduct the study. Therefore, the research procedure in context with this study has been thoroughly described to explain how statistical data were gathered as well as how the approach was used to describe the quantitative nature of this research. The information below will describe the research design and the approach that was followed and how it was applied in the study.

3.2 RESEARCH DESIGN

The research design for this study is a quantitative, cross-sectional, descriptive study design. This design was used to determine the relationship between core stability and athletic performance among university athletes. According to literature, a correlation design is used to determine if there is an association between two or more variables (Thomas *et al*., 2011:20). Extensive data collection was done to gain knowledge in order to determine the significance of core stability in athletic performance and by this, determine the role of core stability training in an overall training program. Data was gathered via quantitative research (a questionnaire and a data collection sheet - cf. Appendix A & B).

Before the commencement of the study, approval was obtained from the Human Science Research Ethical Committee (HSREC) of the Faculty of Health Sciences (FHS) at the UFS and included:

- Head of the Department of Exercise and Sport Sciences, Professor D. Coetzee;
- Dean of the Faculty of Health Sciences, Professor G. van Zyl;
- Dean of Student Affairs, Reverent R. Buys; and
- Vice Rector of Research, Professor C. Witthuhn (cf. Appendix J).

3.3 STUDY POPULATION AND SAMPLE SIZE

Daniel (2012:66), divided sampling into two categories, namely probability sampling and nonprobability sampling, where probability sampling is when the target population gives every element a known and nonzero probability of being selected. However, nonprobability sampling is a procedure that does not give some elements in the population the chance to be in the sample. This study makes use of a probability sample. All the members of the first teams of the UFS were invited to participate in the study.

According to the Kovsie Sport data basis, 140 male and 60 female (n=200) athletes registered at the UFS for the 2017 season representing a first team in the different sport codes. This study only tested 125 male and 52 female athletes (n=177). The remaining 23 all sustained an injury and were therefore not part of the study. The Kovsie Fit gym on campus is an exercise centre facilitating all university athletes in accomplishing their dreams and also accommodates athletes of innumerable kinds of sport. From the sports department, a pre-determined number of 177 athletes were granted a High Performance (HP) package that includes training, testing and personal training assistance at a very low cost. The aim of the facility is to enhance the University's athletes in every possible aspect of their sport and to be able to test the athletes on a regular basis to track their performance. This gives trainers the opportunity to work on the areas in which athletes do not perform at an optimal level yet. All athletes were invited to participate in the study and were allowed to be part of this research project. The researcher, Nelmaré Loubser, went to training sessions to communicate with the conditioning and team coaches of the different sport codes to verbally invite and inform all athletes about the study and the tests that were going to take place. All sports teams were tested in groups on a regular basis as part of their periodisation to track their performance and were informed that the data will be captured anonymously for research purposes.

Convenience sampling was used and all the athletes of the UFS's Sport teams were granted the opportunity to be tested. The sample size had to be large enough to draw a valid correlation between core stability and athletic performance, but costs and time also had to be taken into consideration.

An informed consent form (cf. Appendix E & F) approved by the HRSEC of the FHS at the UFS was explained and handed out to be signed by each athlete. Athletes were included in the study if they fulfilled the following eligibility criteria.

3.3.1 Participation criteria

3.3.1.1 *Inclusion criteria*

- The athletes had to represent one of the university's first teams in the 2017 season.
- The athletes had to be registered at the UFS.
- The athletes had to understand English or Afrikaans to understand how to execute the tests.
- Athletes had to be injury free on the day of testing (no injury that requires any medication or medical care that will impede their results).

3.3.1.2 *Exclusion criteria*

- If the athlete experienced any muscle or abdominal injuries over the last two months that required medical treatment.
- If the athlete was on any medication for a metabolic health condition.
- If the athlete was sick on the day of testing.
- If the athlete was unwilling to give consent to participate in any of the tests.

3.3.1.3 *Withdrawal of study participants*

- If an athlete asked to be removed from the study.
- If the athlete was unable to perform any of the tests they were removed from the study.
- If the athlete developed an injury during the tests impeding their performance.

3.4 TESTING PROCEDURE

Testing took place at the UFS's Sport Science Centre (SSC). This SSC where the testing took place is accredited as an orthopaedic rehabilitation training centre under the regulations of the Health Professions Council of South Africa (HPCSA). The facility is fully equipped with all the relevant apparatus needed in this study. Three qualified biokineticists with 3-10 years of experience in the field of Sport Science and Biokinetics supervised and trained the personnel involved in this project. The testing procedure was for a duration of one hour and the researcher was assisted by the following qualified personnel:

- A level one Anthropometrist - Body Composition;
- Eight Biokinetic interns - Functional testing; and
- Twenty Honor Sport Science Students - Capturing data and Functional testing.

All personnel involved in assisting testing received training in the specific field in order to understand and perform the tests correctly. It was also required of each tester to obtain a Level two Basic Life Support (BLS) certificate, stating that they completed the course in order to assist in medical conditions, should any emergencies occur.

3.4.1 Data collection

Testing of the different sports teams took place on different days as part of training periodization, determined by the conditioning coach. Athletes were tested in groups of twenty to fifty people at a time, depending on the size of the squad. On the day of testing, before any procedures took place, all tests and procedures were verbally explained to all athletes at the SSC of the UFS by the researcher. Before the commencement of testing, all athletes also received an information letter (cf. Appendix C & D) explaining the procedures that were to be followed. Informed consent was given by all athletes before any measurements took place (cf. Appendix E & F) (cf. Figure 3.1 for the summary of the testing procedure). The different sports teams were informed by the conditioning coach, a week before testing, that they were not allowed to do any exercise the previous day or prior to testing and also not to eat something three hours beforehand.

The testing procedure was as follows:

On the day of arrival at the SSC of the UFS, all athletes completed a questionnaire provided by one of the Biokineticists that required the following information:

- Demographic and personal information: Athlete number, date of birth, age and gender.
- Information with regards to the athlete's sport profile: type of sport any previous or current injuries (cf. Appendix A).

This took approximately five minutes to complete.

After completing the questionnaire, all anthropometric measurements and circumferences were conducted using the International Standards for Anthropometric Assessment (ISAAC) method to determine body composition. Measurements were conducted in one of the evaluation rooms in the SSC to ensure privacy. A registered anthropometrist took the skin fold measurements (Marfell-Jones *et al.,* 2006:3) and was assisted by a registered Sport Scientist who took a second measurement to verify the results as required by the ISAAC method. The measurements were taken on the right side of the body in an upright standing position, with the exception of the front thigh skin fold, which was taken in a sitting position. This took approximately ten minutes.

After all questionnaires and skinfold measurements were done, the athlete was assisted by a Sport Science student to warm-up on a Monark cycle ergometer for ten minutes against a 1kg resistance and cadence of 60 repetitions per minute. This was followed by a rest period of three minutes before testing started.

After the warm up, all athletes shifted to the indoor of the SSC where all functional tests were conducted. Firstly, a Biokinetic intern measured core stability by means of a DLLT (Krause *et al.,* 2005:1345; Sharrock *et al.*, 2011:66). This took approximately ten minutes. After a rest period of three minutes, the athlete moved to the next testing station where their performance was measured by means of four different functional tests. The tests included: 1. Vertical jump, 2. T-test, 3. Medicine ball chest throw and 4. Forty-meter sprint (cf. Figure 3.1).

All athletes performed three sets of the whole sequence with a rest period of two minutes between every performance. Each testing station took approximately seven to nine minutes to complete and were assisted by the Sport Science Honour Students and the Biokinetic interns. The principal investigator supervised all the testing to make sure that the testing guidelines were strictly adhered to. After all testing stations were completed, athletes submitted their scoring sheets (cf. Appendix B) to the principal investigator. Data were then logged in on an Excel spreadsheet by the principal investigator for statistical purposes.

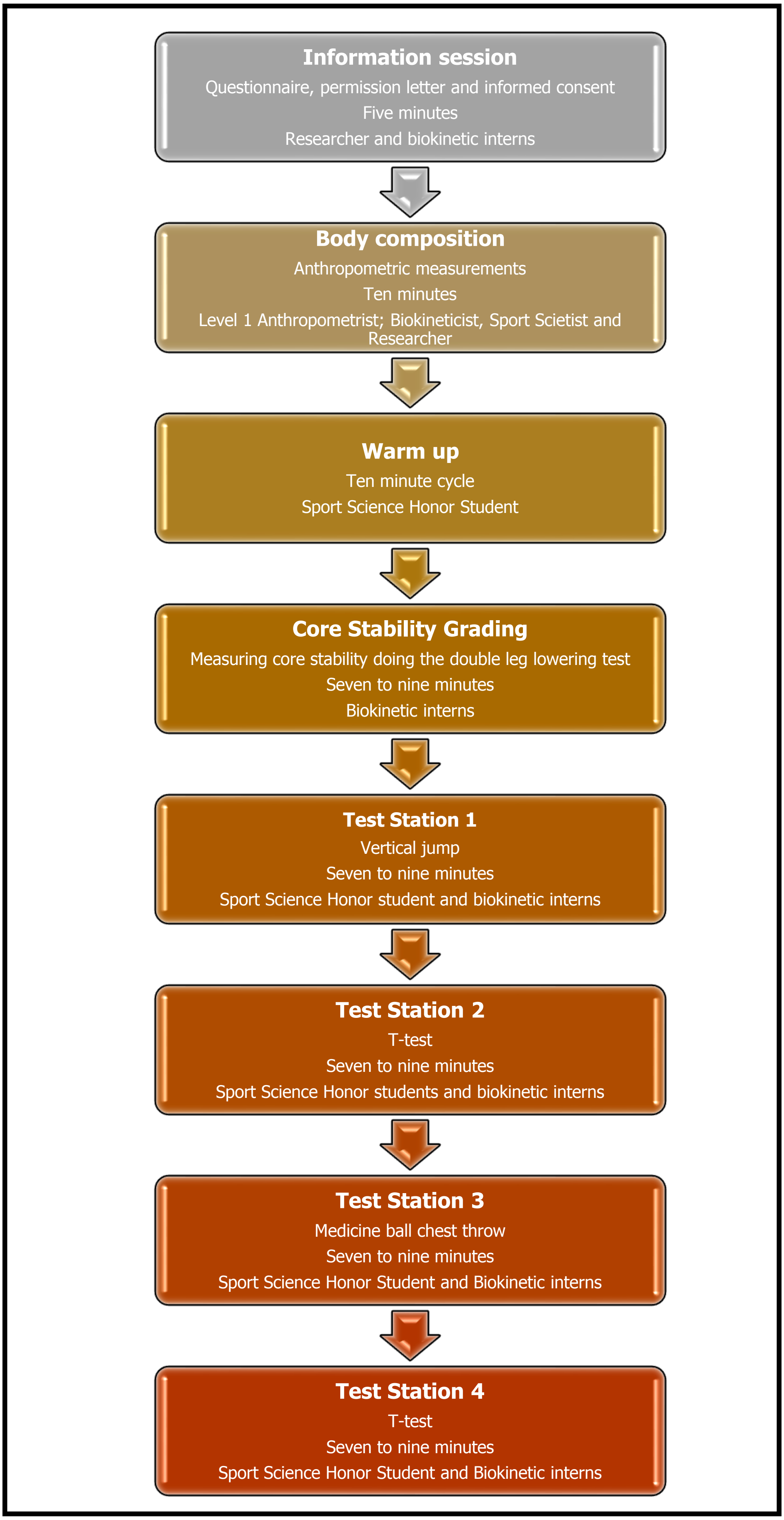

Figure 3.1: Schematic representation of the data collection process

3.4.2 Measurement equipment

All measurement equipment was provided by the SSC.

3.4.2.1 Body fat percentage

The body mass index (BMI) as well as fat percentage was measured by means of a measuring tape, a stadio meter and a Harpenden skinfold calliper. According to Stalker, (2001:24) the reliability of the bone calliper has an ICC= 0.997. The validity of the bone calliper was assessed by Bland-Altman and reflex very high with a 96% agreement between two different methods.

3.4.2.2 The double leg lowering test

The DLLT measured core strength, which served as the test for core stability. It was measured using a double-armed goniometer of transparent plastic and a BPC. The DLLT was used because, as stated by Krause *et al.* (2005:1345), the DLLT activates a variety of muscles replicating the demand of muscle activation during various sports movements and also has increased trunk stabilization due to the position and orientation of the lower limbs during the test. The DLLT has been publicised as a very valid and reliable measure for core stability with an ICC value of 0.98 ($p<0.01$) (Krause *et al.*, 2005:1345). On the other hand, scientists viewed the DLLT as a very subjective test with low validity and reliability even though the EMG activity of the abdominal muscles show substantial activation during the test due to athletes' inability to prevent an anterior pelvic tilt when lowering the legs (Zanotti *et al.*, 2002:435; Halliday, 2011:163). The reliability of the BPC was found to be very high with an ICC = 2.1 (Lanning *et al.*, 2006:427). Core stability has been identified as a critical factor during movement of the lower limbs; therefore, a level of core stability is required to ensure coordination and synchronization of the anterior lower limb and abdominal muscles to ensure coordinated movements (Sharrock *et al.,* 2011:67).

3.4.2.3 The T-test and forty-meter sprint

A stopwatch was used to record the time of the T-test and the forty-meter sprint. Four cones were used as markers to set out the starting and end point for both of these tests. The agility and direction changes during a T-test are compliable in a wide variety of sports with an ICC = 0.98 (Pauole *et al.,* 2000:443). To perform a T-test within the shortest amount of time, the athlete must be able to change direction at a high speed; with enough power to continue at a high velocity when changing direction. The athlete also needs speed as well as optimal agility to complete the course and direction changes within the shortest amount of time (Sharrock *et al.,* 2011:68).

3.4.2.4 The vertical jump

The Vertec was used to determine the height of the vertical jump. It is stated in literature that measuring the vertical jump using the Vertec is one of the most valid and reliable tests with an ICC = 0.82 - 0.99 ($p<0.01$), to determine the explosive power of the lower limbs (Stockbrugger & Haennel, 2001:431).

3.4.2.5 The medicine ball chest throw

A measuring tape was used to determine the distance of the medicine ball chest throw. As found by Stockbrugger and Haennel (2001:431), the reliability of the medicine ball throw is ICC = 0.996 ($p<0.01$). Many sports require overhead activities like throwing a ball or catching an object; therefore, it is important to have a good level of upper body power for optimal performance during these movements (Sharrock *et al.,* 2011:67). Readings were captured and recorded by the use of an E-machine Laptop. Microsoft Excel 2010 was used to capture every individual's data on an individual spreadsheet.

3.5 MEASUREMENT TECHNIQUES

3.5.1 Body composition

The height was measured barefoot, standing in an upright position on a stadiometer, feet shoulder width apart and arms besides the hips. Head is placed against the back of the stadiometer. The athlete was then instructed to take a deep breath. The head board were lowered to the head, pushing down the hair. The reading on the stadiometer indicated the length in cm. Weight was measured on a scale without shoes or heavy clothes. Following body stature, six skinfold measurements were collected and the maximal calf and bicep circumference as well as the circumference of the hips and the middle for calculation of estimated body fat percentage:

Triceps definition: The most posterior part of the Triceps when viewed from the side at the marked mid-acromial-radial level.

Subject position: When marking the sites for the Triceps skinfold, the subject assumed the anatomical position.

Location: The site is marked over the most posterior part of the Triceps when viewed from the side at the marked Mid-acromiale-radiale level.

Figure 3.2: Triceps skinfold (Marfell-Jones *et al.*, 2006:63)

Subscapular

Definition: The site two cm along a line running laterally and obliquely downward from the Sub-scapular landmark at a 45° angle.

Subject position: The subject assumed a relaxed standing position with the arms hanging by the side.

Location: A measuring tape was used to locate the point two cm from the Sub-scapular in a line 45° laterally downward (Marfell-Jones *et al.*, 2006:36).

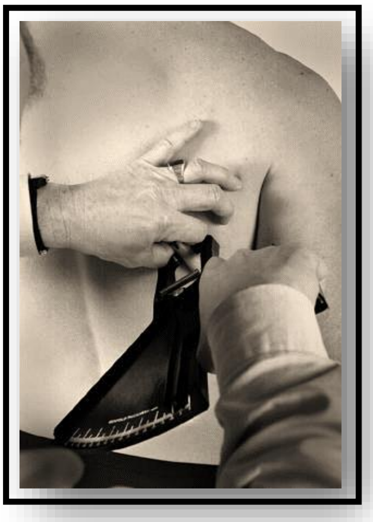

Figure 3.3: Subscapular skinfold (Marfell-Jones *et al.*, 2006:64)

<u>Supraspinale</u>

Definition: The site at the intersection of the line marked the iliospinale to the anterior axillary border and the horizontal line at the level of the iliocristale.

Subject position: The subject assumed a relaxed standing position with the left arm hanging by the side and the right arm abducted to the horizontal after anterior axillary has been identified.

Location: This skinfold runs slightly downward and anteriorly as determined by the natural fold of the skin (Marfell-Jones *et al.,* 2006:39).

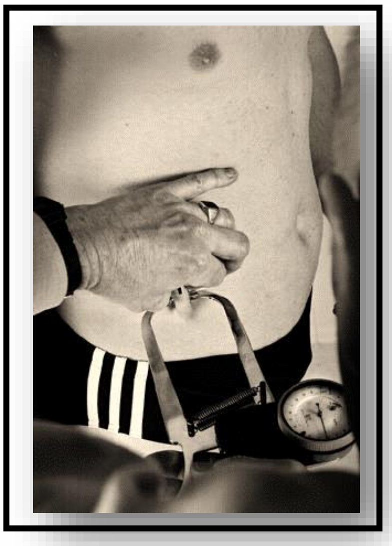

Figure 3.4: Supraspinale skinfold (Marfell-Jones *et al.*, 2006:67)

<u>Abdominal/Para-Umbilicus</u>

Definition: The site five cm to the right-hand side of the omphalion (midpoint of the navel).

Subject position: The subject assumes a relaxed standing position with the arms hanging by the side.

Location: This is a vertical fold raised five cm from the right-hand side of the omphalion (Marfell-Jones *et al.,* 2006:44).

Figure 3.5: Abdominal skinfold (Marfell-Jones *et al.*, 2006:68)

<u>Front thigh</u>

Definition: The site at the mid-point of the distance between the inguinal fold and the anterior surface of the patella on the midline of the thigh.

Subject position: The subject assumes a seated position with the torso erect and the arms hanging by the side. The knee of the right leg should be bent at a right angle.

Location: The measurer stands facing the right side of the seated subject on the lateral side of the thigh. The site is marked parallel to the long axis of the thigh at the mid-point of the distance between the Inguinal fold and the superior margin of the anterior surface of the patella (while the leg is bent). The Inguinal fold is the crease at the angle of the trunk and the thigh. If there is difficulty locating the fold, the subject should flex the hip to make a fold. Place a small horizontal mark at the level of the mid-point between the two landmarks. Now draw a perpendicular line to intersect the horizontal line. This perpendicular line is located in the midline of the thigh. If a tape is used, be sure to avoid following the curvature of the surface of the skin (Marfell-Jones *et al.,* 2006:49).

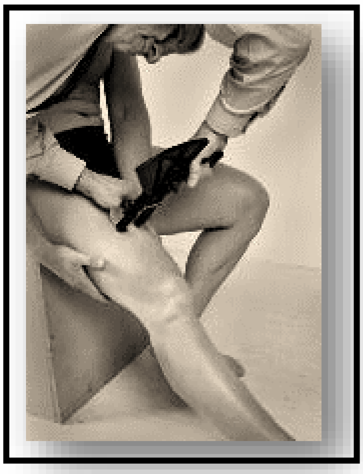

Figure 3.6: Thigh skinfold (Marfell-Jones *et al.*, 2006:70)

<u>Medial calf</u>

Definition: The site on the most medial aspect of the calf at the level of the maximal girth.

Subject position: The subject assumes a relaxed standing position with the arms hanging by the sides. The subject's feet should be separated with the weight evenly distributed.

Location: The level of the maximum girth is determined and marked with a small horizontal line on the medial aspect of the calf. The maximal girth is found by using the middle fingers to manipulate the position of the tape in a series of up or down measurements to determine the maximum girth. View the marked site from the front to locate the most medial point and mark this with an intersecting vertical line (Marfell-Jones *et al.,* 2006:48).

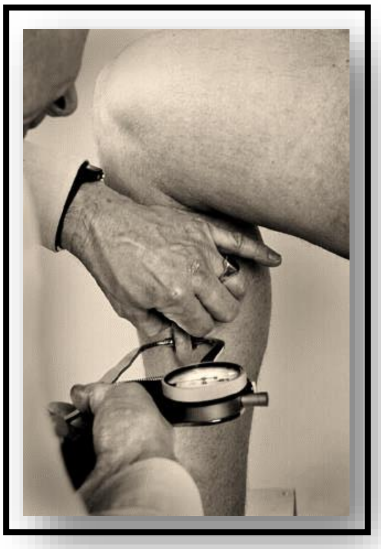

Figure 3.7: Medial calf skinfold (Marfell-Jones *et al.*, 2006:71)

As was advised by Marfell-Jones *et al.* (2006:31-49), care was taken to accurately locate the anatomical landmarks and associated skinfolds. Anthropometric measurements were collected using the pressure calibrated skinfold calliper (Harpenden) and body fat percentages were calculated using the following formulae:

Men: *Body fat percentage= (495/BD) –450*
Body Density (BD) = 1.10326 –0.00031(age) – 0.00036(sum of 6 skinfolds)
Sum of 6 skinfolds = triceps + subscapular + abdominal + supraspinale + thigh + calf (Withers, *et al.*, 1987:192)
Women: *Body fat percentage = (495/BD) –450*
BD = 1.07878 –0.00035(sum of 6 sf) +0.00032(age)

Sum of 6 skinfolds= triceps + subscapular + abdominal + supraspinale + thigh + calf (Withers *et al*., 1987:169).

Athletic performance was determined by measuring athletic ability during functional movements such as the T-test, Vertical jump, forty-meter sprint and the medicine ball chest throw. This included most components required in a wide variety of sport activities similar to explosive power, speed, agility and quickness to determine athletic ability (Sharrock *et al.,* 2011:67).

3.5.2 The double leg lowering test

Abdominal core strength was measured doing the DLLT, which served as the test for core stability (cf. Figure 3.8). Stabilization grading was measured by a Biokinetic intern while the athlete lay in a supine position on a physio bed. During the DLLT, two Biokineticists assisted with testing. Examiner one placed the athlete's legs in a 90° hip flexion. The athlete was then instructed to keep a posterior pelvic tilt and to activate the core muscles in order to keep the back flat on the table when lowering the legs. Palpation of the anterior superior iliac spine (ASIS) and the lumbar spinous processes were used to monitor pelvic neutralization. A BPC inflated to forty mmHg was placed underneath the athlete's back by the second examiner. Examiner one then placed the goniometer on the greater trochanter of the femur, which could have been felt by palpating the lateral side of the hip. The arms of the goniometer were placed parallel to the bed and the longitudinal axis of the femur. The athlete was then asked to lower the legs. If the pressure of the cuff increased or decreased by more than 10 mmHg, the hip angle was measured (Anderson *et al.,* 2014:16).

The rating scale in Functional Testing in Human Performance developed by Kendall was used to determine the values or grading of each athlete (Zannoti *et al*., 2002:433; Reiman & Manske, 2009:233). After a rest period of two minutes, the athlete moved to the second testing station, the vertical jump (cf. Table 3.1).

Table 3.1: Double leg lowering test muscle grading scale

Angle	Muscle grade (nominal scale)	Muscle grade (numerical scale)
0°	Poor	2
15°	Fair	3
30°	Fair plus	3+
45°	Good minus	4-
60°	Good	4
85°	Good plus	4+
90°	Normal	5

(Reiman & Manske, 2009:233)

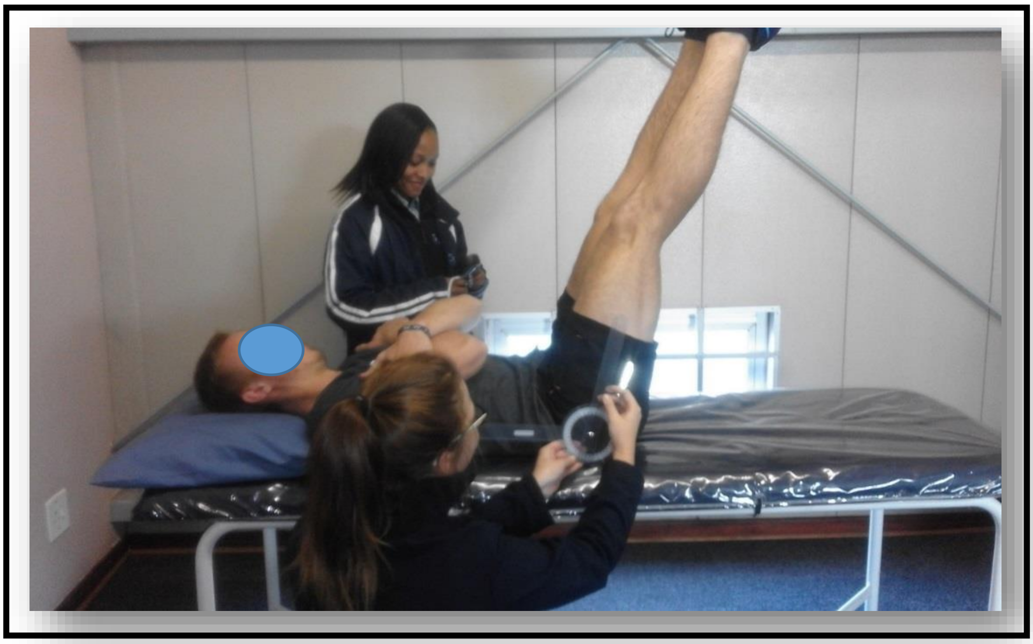

Figure 3.8: The double leg lowering test

3.5.3 The vertical jump

The vertical jump was used to measure lower body power. Many jumping sports require a high level of explosive power of the lower limbs in order to reach certain heights. The athlete was instructed by a Sport Science student to stand perpendicular to the Vertec with weight evenly distributed between both feet. The athlete was not allowed to perform a double bounce before jumping in the air. The athlete was allowed to bend the knees and then jumped from both feet, as high as possible, touching the Vertec (cf. Figure 3.9). The examiner noted the height on a scoring sheet (cf. Appendix B). The athlete then rested for two minutes to ensure optimal recovery and shifted to the third testing station, the T-test.

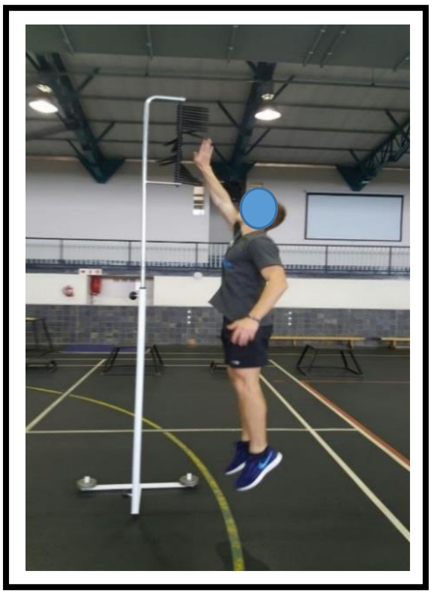

Figure 3.9: The vertical jump

3.5.4 The T-test

Another test conducted by a Sport Science student was the T-test (cf. Figure 3.10). The T-test is a functional test that measures many modalities used in sport, such as lower body speed, agility and quickness during high velocity movements. The athlete was instructed to run ten meters from the start in a northern direction, (1) touched the cone, then side shuffled five meters to the right, (2) touched the next cone, then changed direction and shuffled ten meters to left, (3) touched the cone, changed direction and shuffled back to the middle for five meters; touched the cone and ran backwards to the start for ten meters. The athlete was allowed to do a practice trial to familiarise themselves with the course. After the trial the real test started.

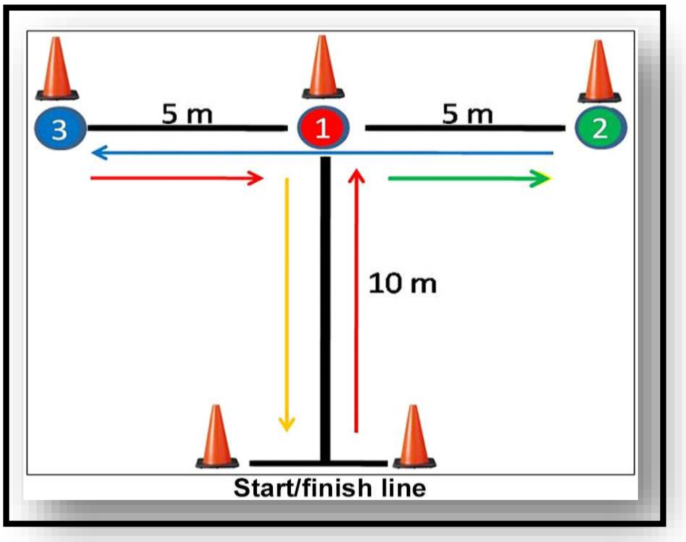

Figure 3.10: Schematic representation of the T-test

Examiner one started the stopwatch as soon as the athlete started to run and stopped the time as soon as the athlete passed the last cone. The time recorded was noted on a scoring sheet (cf. Appendix B) if the athlete completed the test successfully.

Cheating mechanisms like crossing the feet during the side shuffle were not allowed. After a rest period of two minutes, the athlete moved to the next testing station, the medicine ball chest throw.

3.5.5 The medicine ball chest throw

The medicine ball chest throw was used to measure upper body power (cf. Figure 3.11) (Sharrock *et al.,* 2011:68). For the completion of this test, the athlete was instructed by a

Sport Science Student to stand in a kneeling position with knees bent ninety degrees and both hips fully extended. A distance of forty-meters was measured out with a measuring tape. The athlete held a 5kg medicine ball in front of the chest. When the athlete was ready, they threw the ball as far forward as possible without falling forward or rocking back to gain momentum before the throw.

Each athlete was granted a practice trial to ensure they understood the movement correctly. If the movement was carried out correctly without any compensation, the distance of the first bounce was measured and recorded by the Sport Science Student on a scoring sheet. (cf. Appendix B). The athlete again rested for two minutes to ensure optimal recovery and then moved to the fourth testing station, the forty-meter sprint.

Figure 3.11: The medicine ball chest throw

3.5.6 The forty-meter sprint

The forty-meter sprint test was used to measure lower body power and speed (Seiler *et al.*, 2009:9). For an athlete to complete a forty-meter sprint within the shortest amount of time, requires optimal power to begin the movement and maximal speed to accelerate to maximum speed, as quickly as possible (Sharrock *et al.,* 2011:67). To start this test, the athlete was instructed by a Sport Science student to cover a distance of forty-meter as fast as possible. Cones were set out to mark the distance. The time was recorded by a Sport Science student from the first limb movement and terminated as soon as the athlete crossed the line. The time was captured on a scoring sheet (cf. Appendix B).

After completion of all the different tests, all sheets were collected from the athletes by the principal investigator. Data were kept confidential and were logged in on an Excel sheet by the principal investigator.

3.6 METHODOLOGICAL AND MEASUREMENT ERRORS

According to literature, validity is the degree to which the test or study is able to measure what it sets out to measure (Reiman & Manske, 2009:4). Test protocols and regulations were followed for speed, power, agility and core testing as set out by Sharrock *et al.* (2011:67). When performing clinical and functional testing and assessments, the researcher had to be cautious when performing each test. Many factors had to be taken into consideration when testing these modalities. Factors that may influence results are: exercise the day or few days prior to testing, time of the day testing occurs, sequence of testing, inconsistencies in the use of rules and regulations during data gathering, insufficient rest between each test or inexperience of the researcher and poor in knowledge/technique (Baumgartner *et al.,* 2006:72).

For the abovementioned reasons, the Researcher, Nelmaré Loubser, made sure that all athletes were informed in the participation invite to rest the day prior to testing. The researcher was also responsible for ensuring that all the personnel understood the rules and regulations of each test and that strict judgement be used when tests were conducted. Enough rest was given between the different testing stations to ensure optimal results and all tests were done in the morning while athletes were still energized. To ensure internal reliability and positive results, each athlete completed the testing sequence three times.

Another factor that can play a critical role in athletic performance is muscle fatigue. Lack of sleep and calorie intake is two of the biggest factors influencing muscle recovery; therefore, athletes were instructed to take a good night's rest of at least eight hours of sleep and a balanced calorie intake, before commencement of data collection (cf. Appendix B). Body composition was measured according to the International Standards for Anthropometric Assessment method (Marfell-Jones *et al.*, 2006:31-50). To minimise discrepancy between two measurements, a permanent marker was used by the Biokinetic interns to mark a cross on the skin where the measurement was to be taken. This served as a guide for calliper placement to ensure consequent measurements. The Anthropomitrist individually measured each athlete.

3.7 DATA ANALYSIS

According to researchers, data analysis is the systematic synthesis and organisation of research data that assists the researcher in reducing, organising and giving significance to data (Polit & Beck, 2006:498). Data was captured electronically by the researcher on Microsoft Excel (Microsoft Office, 2010). Further analysis was done by Prof Schall, a biostatistician from the UFS's Statistical Consultation Unit using SAS Version 9.1.3. Descriptive statistics was provided for all collected data, namely mean Standard deviation (STD), minimum, median and maximum values for quantitative data and counts and percentages for categorical data. Correlations between the DLLT and each of the four performance tests were determined, overall and separately by gender and sport. Furthermore, the effect of core stability on athletic performance measures were assessed using ANCOVA, fitting the factors sport and gender and the covariates age, height, weight, BMI and fat% of the athletes, as well as relevant interaction terms.

This study used Cohen's correlation scale to determine the degree of correlation between all the performance variables and the DLLT (Cohen, 2006:online).

Table 3.2: Cohen's correlation scale of magnitudes for effect statistics

Correlation Coefficient	Descriptor
0.0-0.1	Trivial, very small, insubstantial, tiny, practically zero
0.1-0.3	Small, low, minor
0.3-0.5	Moderate, medium
0.5-0.7	Large, high, major
0.7-0.9	Very large, very high, huge
0.9-1	Nearly, practically, or almost: perfect, distinct, infinite

(Cohen, 2006:online).

3.8 PILOT STUDY

Thomas *et al.* (2011:278) states that it is critical to conduct a pilot study to identify possible problems or pitfalls in the proposed technique. This process is generally referred to as a pilot study. According to research, the reason for conducting a pilot study is for pre-testing a particular research instrument (Van Teijlingen & Hurdley, 2001:289). By conducting a pilot study, the researcher might have been given advance warning about where the main research project could have failed, where research protocols may not be followed and whether proposed methods or instruments were inappropriate or too complicated (Van Teijlingen & Hurdley, 2001:289). A pilot study was planned as soon as the researcher received ethical clearance. The pilot study was implemented and included four functional tests and the DLLT (core stability). During the pilot study, the researcher's aim was to test at least five voluntary athletes taking part in sport for the UFS. The pilot study results were not included in the final research.

3.9 TIME SCHEDULE

Table 3.3: Estimated time schedule for submitting the protocol

Sub division	Estimated time
Literature review	February - June 2016
Writing the protocol	June-August 2016
Evaluation committee	December 2016
Submission for ethical clearance	April 2017
Ethical aspects	Ethical clearance to be approved by the UFS ethical committee in April
Testing	Complete- August 2017
Analysis of data completed	November 2017
Writing up	December –January 2018

3.10 BUDGET

Table 3.4: Total estimated costs for submitting the dissertation

Item	Estimated cost	Quantity	Total estimated cost
Consent and information letter	R1 per copy (3 pages per set)	840 pages	R840
Binding the protocol	R20	6	R120
Binding the thesis	R90	4	R360
Language editing	R5000	1	R5000
Scoring sheets	R1 per copy (2 pages per athlete)	560 pages	R560
Petrol	R13.60/l (10km/l)	100km	R136
Total			**R7016**

The researcher was responsible for all the costs.

3.11 ETHICAL APPROVAL

Before commencement of the study, ethical clearance was obtained from the Director of Kovsie Sport, Mr D.B. Prinsloo (cf. Appendix F), the Manager of the SSC, Mrs T. Pittaway (cf. Appendix E) as well as the HSREC at the UFS, which consisted of the following:

- Head of the department of Exercise and Sport Sciences - Professor D. Coetzee;
- Dean of the Faculty of Health Sciences - Professor G.J. van Zyl;
- Dean of Student Affairs - Referent Rudy Buys; and

- Vice Rector of Research - Professor C. Witthuhn.

3.12 IMPLEMENTATION OF DATA

The findings of the planned study will contribute to the body of knowledge by quantifying the correlation between core stability and functional performance among athletes. It will also assist in identification of factors associated with athletic performance and informing athletes and exercise specialists about possible ways to improve exercise programmes in order to improve athletic performance.

CHAPTER 4

RESULTS

4.1 INTRODUCTION

The purpose of this study was to identify the association between core stability and athletic performance measures such as the (1) Vertical jump test, (2) T-test, (3) Forty-meter sprint test and the (4) Medicine ball chest throw test. Data were collected from 177 (n=177) university athletes playing rugby, hockey, soccer, basketball and cricket during the 2017 sport season. This chapter will present the results of the study. The interpretation and the discussion of the findings will follow in Chapter 5.

4.2 DEMOGRAPHICAL INFORMATION OF ATHLETES

4.2.1 Participants

Two hundred university athletes (when referring to athletes of a specific sport, the term "players" was used, whereas the term "athletes", refers to all athletes in general) were registered for the 2017 sport season. Twenty-three (12%) athletes did not qualify for testing due to injuries they sustained within the last two months; therefore 177 of the 200 athletes (88.5%) were tested. Table 4.1 presents the number of athletes by sport and gender.

The demographic information displayed in this section provides an overview of the cohort of athletes. Of the 177 participants, 71% (n=125) were males and 29% (n=52) females, while the age of the total sample ranged from 17 – 30 years, with a mean of 20.32 (±2.15) years.

Table 4.1: Number of athletes by gender and sport

Gender	Rugby	Hockey	Soccer	Basketball	Cricket	Total
Male	61	20	19	9	16	125
Female		20	17	15		52
Total	61	40	36	24	16	177
% Total	34%	23%	20%	14%	9%	100%

4.2.2 Biographical information and anthropometric measurements

Figures 4.1 - 4.5 present box plots of the variables age, weight, height, BMI and body fat percentage of athletes, by gender and type of sport. Detailed descriptive statistics for the same variables are presented in Table 4.2. Box plots illustrate the distribution of the variable that is plotted: The data boxes display the range from the first to the third quartile of the data and thus represent the central 50% of the data. The whiskers attached to the boxes are drawn from the box to the most extreme point that is less than or equal to 1.5 times the inter-quartile range (IQR) (IQR: the difference between the third and first quartile). If the highest or lowest values are more than 1.5 times the IQR from the box, they are represented by a "+" or a "o" sign.

4.2.2.1 *Age*

Box plots illustrate the distributions of the age (cf. Figure 4.1) of athletes by gender and sport. Detailed descriptive statistics for this variable is presented in Table 4.2.

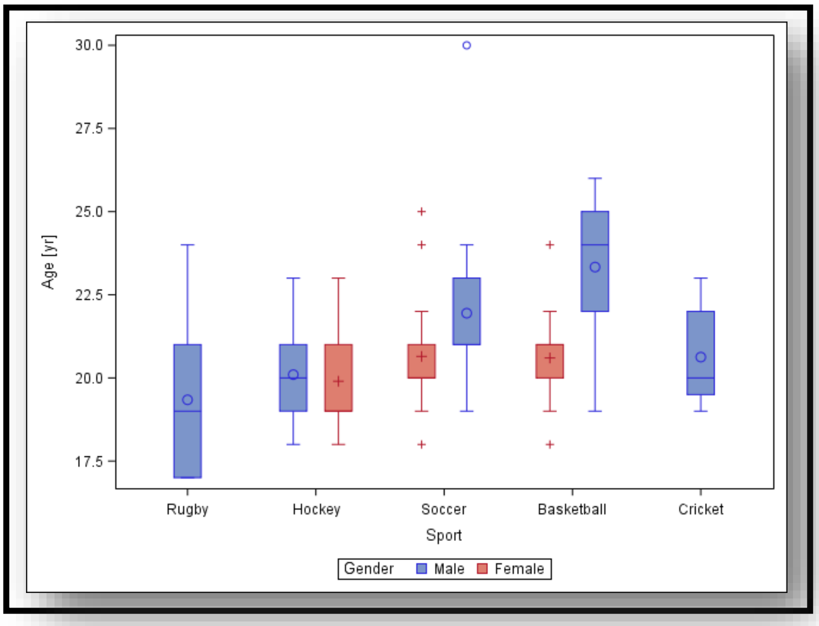

Figure 4.1: Box plot: Age of athletes, by gender and type of sport

As can be seen from Figure 4.1 (gender and sports considered separately), the age range of athletes within the specific sports is generally quite narrow, with the exception of male rugby and basketball players. Furthermore, in males, the lower quartile of the age, for both soccer and basketball players are equal or higher than the higher quartile of the other sports, suggesting that, in general, male soccer and basketball players tend to be older than athletes in other sports. On the other hand, rugby players tend to be considerably younger than the athletes in other sports. As seen in Table 4.2, the oldest male soccer and basketball players were 30 and 26 years of age respectively, while all the athletes of the other sports, males and females, had a maximum age of 25 years. Furthermore, the mean age of both male and female athletes in all sports was between 19 and 20 years, while male soccer and basketball players had a mean age of 22 and 23 years respectively. All athletes participated in a first university sports team.

4.2.2.2 *Height and weight*

Box plots illustrate the distributions of the variables height and weight (cf. Figure 4.2 & 4.3) of athletes by gender and sport. Detailed descriptive statistics for these variables are presented in Table 4.2.

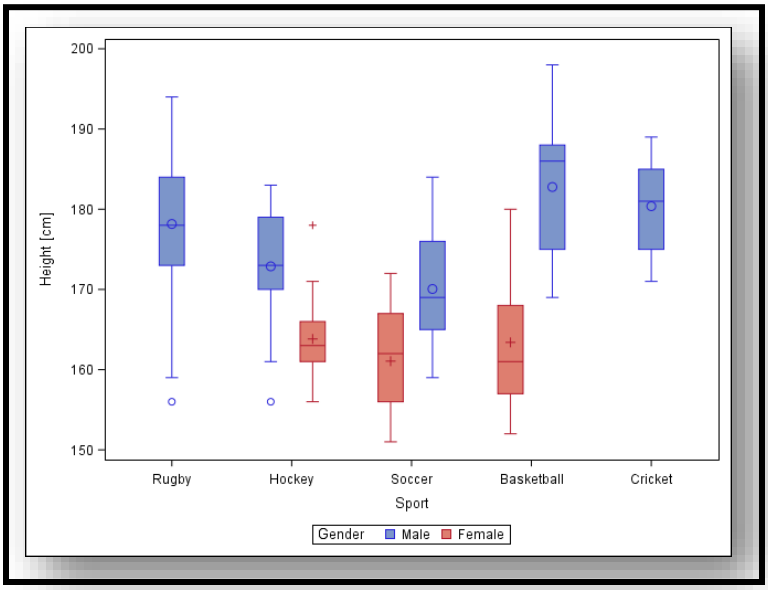

Figure 4.2: Box plot: Height of athletes, by gender and type of sport

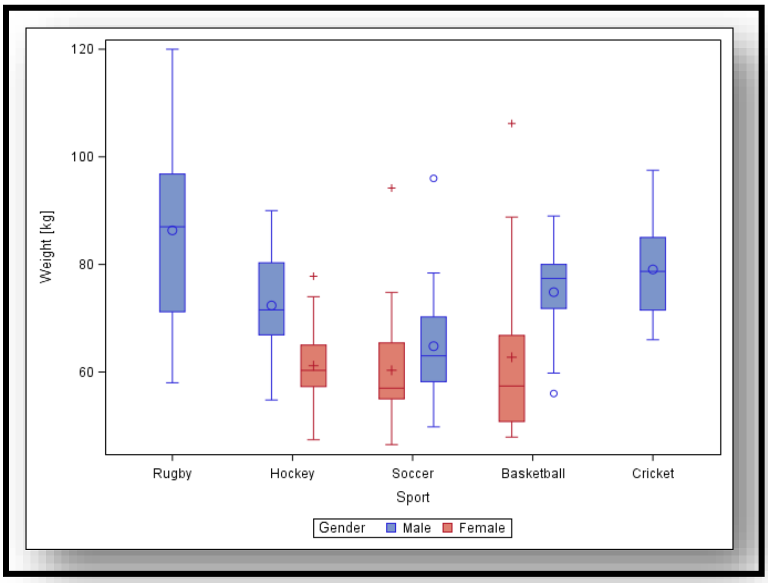

Figure 4.3: Box plot: Body weight of athletes, by gender and type of sport

As can be seen from Figure 4.2 (gender and sports considered separately), the height of the male athletes within the specific sports varied considerably among the players and also between the different sports. In females, the results look similar, with the exception of hockey players that show a narrow distribution, indicating that hockey players tend to have similar body statures. Furthermore, among the different sports, the upper quartile of the height in female athletes is either lower than the lower quartile or just above the lower quartile of the height in males, suggesting that, in general, female athletes are relatively shorter than their male counterparts. The mean height for male and female athletes was 176.7cm (±8.38cm) and 162.8cm (±6.74cm) respectively (cf. Table 4.2). In females, among the different sports, the inter quartile of the height of athletes overlaps, which indicate that there are no significant differences between the height of female hockey, soccer and basketball players. The mean heights of these players are 163.8cm, 161.1cm and 163.4cm respectively. Among the males, on the other hand, basketball (182.8cm) tends to have the tallest players, whereas soccer (170.1cm) has the shortest players.

When stratified by weight (gender and sports considered separately), Figure 4.3 suggests that players within the same sport tend to have similar weight, with the exception of rugby players that show quite a big difference in weight among the players. This could be connected to the playing positions. In males, the lower quartile of the weight of rugby players is higher than the upper quartile of the weight of soccer players, suggesting that, in general, male rugby players are much heavier than soccer players and that it is also the sport with the heaviest players (86kg), while soccer tends to have the lightest players (65kg). This can be due to the morphologic composition of athletes as well as the demands of the sport. The mean weights of male hockey (72kg) and basketball (74kg) players were very similar, while cricket (79kg) players were a bit heavier.

Female athletes, on the other hand, all have similar weights among the athletes of the different sports, with the exception of basketball, showing a big variation in weight among the players (62kg ±17kg). Similarly, as seen in Figure 4.3, the inter quartile of the weight of the female athletes overlaps, which indicates that there is no significant difference between the weight of hockey, soccer and basketball female players, with mean values of 61kg, 60kg and 62kg respectively (cf. Table 4.2). Similarly to height, female athletes are much lighter than their male counterparts in all sports, for the female upper quartiles of body weight are lower than the upper or lower quartiles of body weight of males in all sports.

4.2.2.3 *BMI and body fat percentage*

Box plots illustrate the distributions of the variables BMI and body fat percentage (cf. Figure 4.4 & 4.5) of athletes by gender and sport. Detailed descriptive statistics for these variables are presented in Table 4.2.

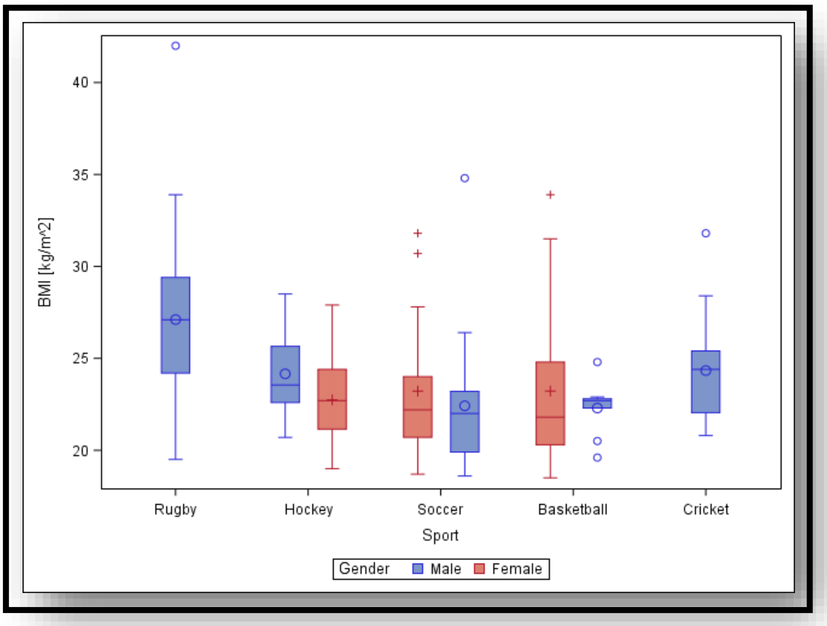

Figure 4.4: Box plot: BMI of athletes, by gender and type of sport

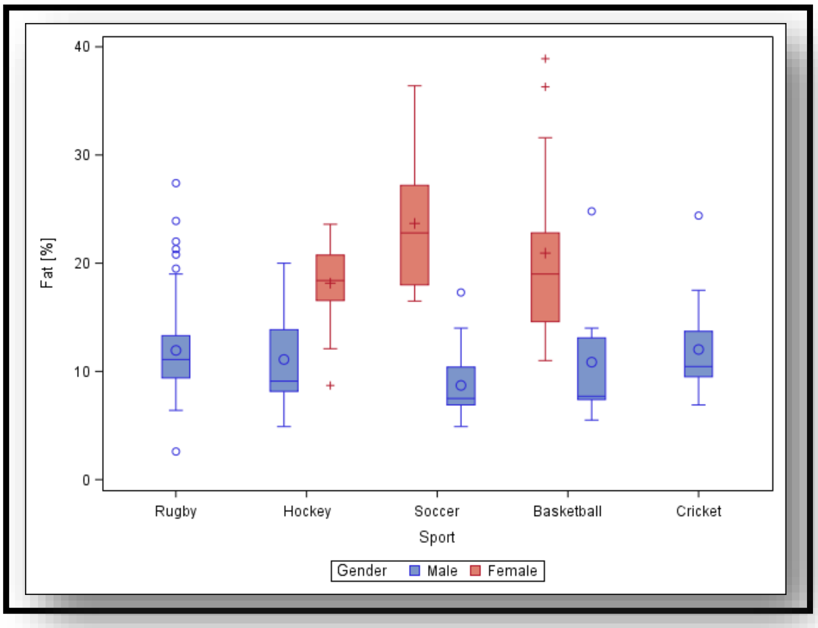

Figure 4.5: Box plot: Body fat percentages of athletes, by gender and type of sport

As seen in Figure 4.4 (gender and sport considered separately), male basketball players tended to have the same BMI, while male hockey, soccer and cricket players had a bigger BMI distribution. On the other hand, the BMI of male rugby players generally tended to vary considerably among the players, with a minimum and maximum BMI of 19.5 kg/m^2 and 42 kg/m^2 respectively. In females, the inter quartile of the BMI of athletes overlaps, which indicate that there are no significant differences between the BMI of female hockey, soccer and basketball players. The mean BMI values for female hockey, soccer and basketball players are 22.74 kg/m^2, 23.22 kg/m^2 and 23.22 kg/m^2 respectively. Furthermore, female soccer and hockey players have a narrow BMI distribution among the athletes, whereas basketball players' BMI vary considerably more among the team. As seen in Table 4.2, male rugby players (27.11 kg/m^2) had the biggest BMI and basketball (22.30 kg/m^2) and soccer (22.42 kg/m^2) the smallest. Hockey (24.16 kg/m^2) and cricket (24.33 kg/m^2), on the other hand, were very similar. Overall, rugby players also appear to have a much bigger BMI than the male athletes of the other sports with a max BMI of 42 kg/m^2, while males of other sports had a max BMI of 34.8 kg/m^2. Although females appeared shorter than their male counterparts and also weighed less, their BMI's were higher for both soccer (23.22 kg/m^2) (22.42 kg/m^2) and basketball (23.22 kg/m^2) (22.30 kg/m^2), but lower in hockey players (22.74 kg/m^2) (24.16 kg/m^2) (cf. Table 4.2).

As seen in Figure 4.5 (gender and sport considered separately), all male athletes had more or less the same body fat percentage regardless of the sport, whereas the body fat percentage of females in different sports varied considerably. Soccer and basketball also show a wide difference in body fat percentage among the female athletes of these two sports; however, hockey seems to differ. Furthermore, the lower quartile of the body fat percentage of all the female sports is higher than the upper quartile of the body fat percentage of their male counterparts, suggesting that females tend to have more body fat than their male counterparts even though female athletes are much smaller in height and weight. The total mean body fat percentage for male and female athletes was 11.25% (±4.6%) and 20.76% (±6.47%) respectively. Furthermore, Table 4.2 illustrates that, when comparing body fat percentages, male soccer players (8.71%) had the least body fat, while cricket players (12.03%) had the most. Rugby (11.94%), hockey (11.11%) and basketball (10.86%) players present very similar body fat percentages.

Table 4.2: Descriptive statistics for demographic variables: Overall, by gender, by type of sport and for each combination of gender and type of sport
(Table continues on next page...)

Variable	Statistic	All Sports			Rugby	Hockey		Soccer		Basketball			Cricket
		All	**F**	**M**	**M**	**F**	**M**	**F**	**M**		**F**	**M**	**M**
Age [yr]	**N**	**177**	**52**	**125**	**61**	**20**	**20**	**17**	**19**		**15**	**9**	**16**
	Mean	20.32	20.35	20.31	19.34	19.90	20.10	20.65	21.95		20.60	23.33	20.63
	Std	2.15	1.55	2.36	2.09	1.37	1.59	1.77	2.37		1.45	2.55	1.50
	Min	17.00	18.00	17.00	17.00	18.00	18.00	18.00	19.00		18.00	19.00	19.00
	Q1	19.00	19.00	19.00	17.00	19.00	19.00	20.00	21.00		20.00	22.00	19.50
	Median	20.00	20.00	20.00	19.00	19.00	20.00	20.00	21.00		21.00	24.00	20.00
	Q3	21.00	21.00	22.00	21.00	21.00	21.00	21.00	23.00		21.00	25.00	22.00
	Max	30.00	25.00	30.00	24.00	23.00	23.00	25.00	30.00		24.00	26.00	23.00
Length [cm]													
	Mean	172.62	162.80	176.70	178.16	163.83	172.87	161.06	170.05		163.40	182.78	180.38
	Std	10.15	6.74	8.38	7.96	4.71	6.85	6.93	7.08		8.65	10.02	5.74
	Min	151.00	151.00	156.00	156.00	156.00	156.00	151.00	159.00		152.00	169.00	171.00
	Q1	164.00	158.00	172.00	173.00	161.00	170.00	156.00	165.00		157.00	175.00	175.00
	Median	173.00	162.75	176.00	178.00	163.00	173.00	162.00	169.00		161.00	186.00	181.00
	Q3	180.00	167.00	182.00	184.00	166.00	179.00	167.00	176.00		168.00	188.00	185.00
	Max	198.00	180.00	198.00	194.00	178.00	183.00	172.00	184.00		180.00	198.00	189.00
Weight [kg]													
	Mean	73.86	61.34	79.07	86.34	61.17	72.36	60.32	64.80		62.74	74.84	79.06
	Std	16.33	12.02	15.03	15.20	7.46	9.47	11.32	10.96		17.34	10.84	8.93
	Min	46.50	46.50	49.80	58.00	47.40	54.80	46.50	49.80		47.90	56.00	66.00
	Q1	59.80	54.90	68.00	71.20	57.30	66.90	55.00	58.20		50.80	71.80	71.50
	Median	70.80	57.90	77.60	87.00	60.30	71.55	57.00	63.00		57.40	77.40	78.70
	Q3	85.00	65.20	90.40	96.80	65.00	80.30	65.40	70.23		66.80	80.00	85.00

	Max	120.00	106.20	120.00	120.00	77.80	90.00	94.20	96.00		106.20	89.00	97.50
BMI [kg/m^2]												
	Mean	24.58	23.03	25.22	27.11	22.74	24.16	23.22	22.42		23.22	22.30	24.33
	Std	3.99	3.42	4.04	4.15	2.22	2.42	3.73	3.71		4.46	1.49	2.99
	Min	18.50	18.50	18.60	19.50	19.00	20.70	18.70	18.60		18.50	19.60	20.80
	Q1	21.70	20.70	22.30	24.20	21.15	22.60	20.70	19.90		20.30	22.30	22.05
	Median	23.50	22.20	24.50	27.10	22.70	23.55	22.20	22.00		21.80	22.70	24.40
	Q3	27.10	24.40	27.70	29.40	24.40	25.65	24.00	23.20		24.80	22.80	25.40
	Max	42.00	33.90	42.00	42.00	27.90	28.50	31.80	34.80		33.90	24.80	31.80
Fat percentage [%]												
	Mean	14.04	20.76	11.25	11.94	18.16	11.11	23.68	8.71		20.93	10.86	12.03
	Std	6.69	6.47	4.42	4.46	3.59	4.19	6.16	3.09		8.45	5.98	4.27
	Min	2.60	8.70	2.60	2.60	8.70	4.90	16.50	4.90		11.00	5.50	6.90
	Q1	9.00	16.75	8.20	9.40	16.55	8.15	18.00	6.90		14.60	7.40	9.50
	Median	12.10	19.70	10.20	11.10	18.40	9.10	22.80	7.50		19.00	7.70	10.45
	Q3	17.60	22.80	13.20	13.30	20.75	13.85	27.20	10.40		22.80	13.10	13.70
	Max	38.90	38.90	27.40	27.40	23.60	20.00	36.40	17.30		38.90	24.80	24.40

4.3 CORE STABILITY

Box plots illustrate the distributions of the core stability (DLLT) (cf. Figure 4.6) of athletes by gender and sport. Detailed descriptive statistics for this variable is presented in Table 4.3.

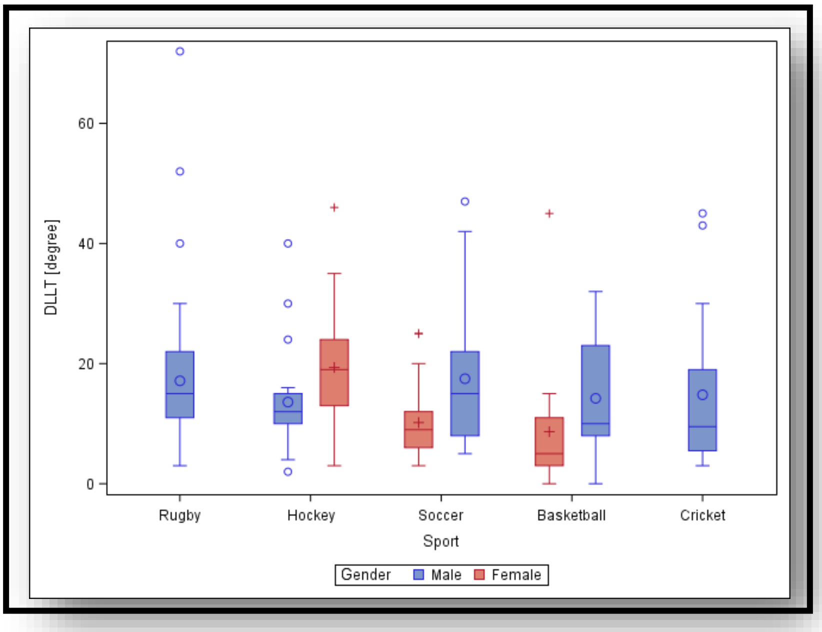

Figure 4.6: Box plot: Core stability (DLLT) of athletes, by gender and type of sport

As can be seen in Figure 4.6 (gender and sport considered separately), in male athletes, core stability (DLLT) vary much among the athletes of the specific sports, with the exception of hockey that shows a small distribution among the players, with an upper and lower value of 10° and 15°. However, the inter quartile of core stability (DLLT) of the different sports overlap, indicating that there is no significant difference between the degree of core stability (DLLT) of male athletes among different sports. In females, basketball and soccer had a narrow core stability (DLLT) distribution among the players, while hockey had a bigger distribution, with Q1 and Q3 values of 13° and 24° respectively. The lower quartile of the degree of core stability (DLLT) of female hockey players is also higher than the upper quartile of the degree of core stability (DLLT) of females, in both soccer and basketball, suggesting that in general, hockey players tend to have a better degree of core stability (DLLT) than basketball and soccer players.

Both the basketball and soccer male box plots are higher than those of the females, indicating that males regularly may had a better degree of core stability (DLLT) than females. However, this contradicts the findings of Sharrock *et al.* (2011:70), who found that females have a better degree of core stability (DLLT) than males.

However, in hockey the opposite is noticeable with the lower quartile of the degree of core stability (DLLT) of females almost level with the upper quartile of the degree of core stability (DLLT) of males. The mean degrees of core stability (DLLT) for male and female athletes were 16.11° (±11.28°) and 13.27° (±10.63°) respectively (cf. Table 4.3). Furthermore, among the different sports, all males reveal a better degree of core stability (DLLT) than their female counterparts, except in hockey, that reveals a mean degree of core stability (DDLT) of 19.35° and 13.60° for female and male athletes respectively. Male soccer players (17.47°) had the highest mean degrees of core stability (DLLT) and hockey (13.60°) the lowest. Rugby (17.13°) is similar to soccer, whereas basketball (14.22°) and cricket (14.81°) are similar to hockey. Although all the other female sports had a lower degree of core stability (DLLT) than their male counterparts, female hockey players (19.35°) had the highest mean degree of core stability (DLLT), also higher than males (13.6°) and female basketball (8.67°) and soccer (10.18°) the lowest.

Table 4.3: Descriptive statistics for the DLLT: Overall, by gender, by type of sport and for each combination of gender and type of sport

Variable	Statistic	All Sports			Rugby	Hockey		Soccer		Basketball			Cricket
		All	F	M	M	F	M	F	M		F	M	M
DLLT [°]	N	177	52	125	61	20	20	17	19		15	9	16
	Mean	15.28	13.27	16.11	17.13	19.35	13.60	10.18	17.47		8.67	14.22	14.81
	Std	11.14	10.63	11.28	11.42	10.31	8.93	6.93	11.89		11.18	10.44	13.50
	Min	0.00	0.00	0.00	3.00	3.00	2.00	3.00	5.00		0.00	0.00	3.00
	Q1	7.00	5.00	8.00	11.00	13.00	10.00	6.00	8.00		3.00	8.00	5.50
	Median	14.00	10.00	15.00	15.00	19.00	12.00	9.00	15.00		5.00	10.00	9.50
	Q3	21.00	19.50	22.00	22.00	24.00	15.00	12.00	22.00		11.00	23.00	19.00
	Max	72.00	46.00	72.00	72.00	46.00	40.00	25.00	47.00		45.00	32.00	45.00

4.4 PERFORMANCE TESTS

4.4.1 The vertical jump

Box plots illustrate the distributions of the vertical jump (cf. Figure 4.6) of athletes by gender and sport. Detailed descriptive statistics for this variable is presented in Table 4.4.

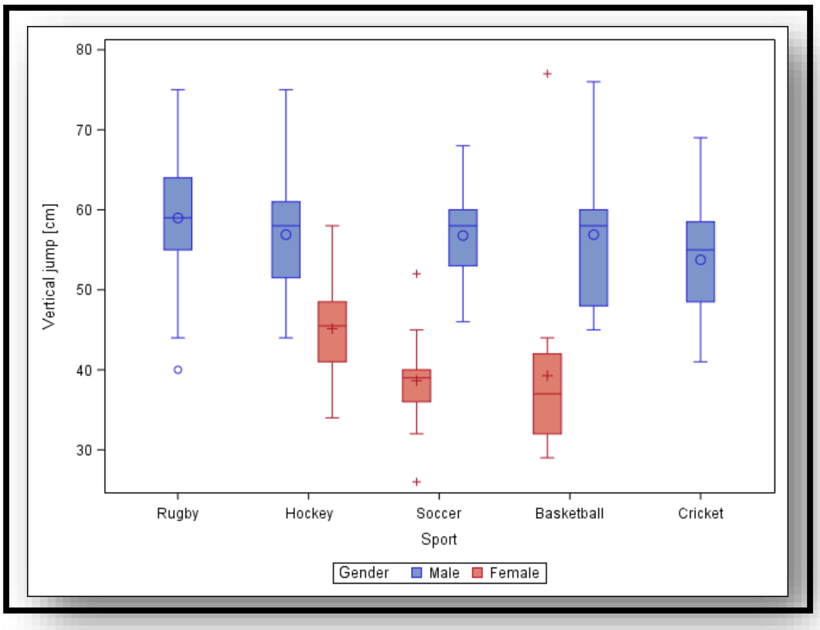

Figure 4.7: Box plot: Vertical jump height of athletes, by gender and type of sport

As seen in Figure 4.7 (gender and sport considered separately), athletes tend to jump similar heights within the specific sports; however, the heights differ between the athletes of different sports. Furthermore, the lower quartile of vertical jump height of male athletes of all the different sports are higher than the upper quartile of the vertical jump height of all their female counterparts, indicating that in general, males jump higher than females, as would be expected. In males, the inter quartile of the vertical jump height of all sports overlap, suggesting that there is no significant difference in the height of the vertical jump between male rugby, hockey, soccer, basketball and cricket players; however, basketball players tend to have a bigger vertical jump height variance among the players than the other sports.

In females, although the height of the vertical jump varies considerably among the players of the different sports, the height of players within the specific sports are very similar - which might be due to the demands of the sport or other contributing factors such as weight or body fat percentage. The female plots also indicate outliers among both soccer (26cm) and basketball (77cm) players, with the outlier of basketball with the highest overall jump score and soccer the lowest overall jump score, among all the athletes.

Furthermore, the mean vertical jump score for male and female athletes was 57.50cm (±7.75cm) and 41.33cm (±8.27cm) respectively. The mean vertical jump score for men in rugby (58.9 cm) was the highest and cricket (53.7cm) the lowest. Hockey (56.9cm), soccer (56.7cm) and basketball (56.5cm) scores were very similar. However, as expected, the female athletes' mean vertical jump scores were much lower than that of their male counterparts. Hockey players scored the highest (45.15 cm) and basketball (39.27 cm) and soccer (38.65 cm) the lowest in terms of vertical jump height.

4.4.2 The medicine ball chest throw

Box plots illustrate the distributions of the chest throw (cf. Figure 4.8) of athletes by gender and sport. Detailed descriptive statistics for this variable is presented in Table 4.4.

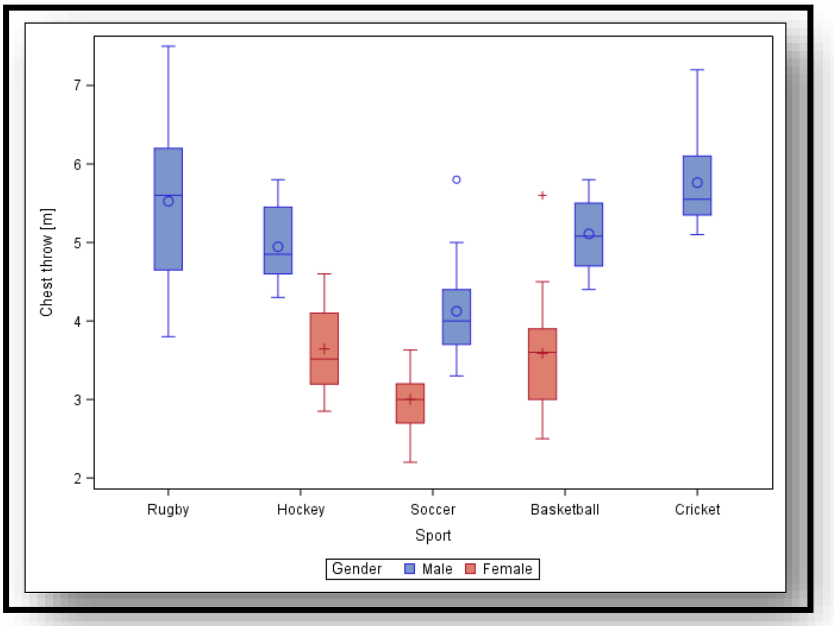

Figure 4.8: Box plot: Medicine ball chest throw distance of athletes, by gender and type of sport

As seen in Figure 4.8 (gender and sport considered separately), there is a narrow distribution within the specific sports, indicating that athletes partaking in the same sport tended to throw similar distances; however, distances vary considerably among athletes of different sports. Rugby is the only sport with a broader distribution, suggesting that rugby players tend to throw different distances among the players, with a Q1 and Q2 value of 4.7m and 6.2m respectively and it might be that forwards, for example, have more upper body power than back line players. Furthermore, the lower quartile of the chest throw of the males in all the different sports are higher than the upper quartile of the chest throw of the females in all the different sports, suggesting that, in general, males tend to throw much further than females. Table 4.4 reveals overall (genders considered separately) mean medicine ball chest throw scores of 5.22m (±0.94m) and 3.42m (±0.65m) for male and female athletes respectively.

The lower quartile of the chest throw of male rugby, hockey, basketball and cricket players is higher than the upper quartile of the chest throw of male soccer players, suggesting that rugby, hockey, basketball and cricket players tend to have much more upper body power than soccer players.

However, cricketers in general tend to have the most upper body power - which is quite understandable when considering the demands of the sport. The mean values for rugby, hockey, basketball, cricket and soccer are - 5.5m, 5m, 5.1m, 5.8m and 4.1m respectively (cf. Table 4.4).

Similarly, in females, the lower quartile of the chest throw of hockey and basketball players is equal or just below the upper quartile of the chest throw of female soccer players, indicating that the same is true among the female athletes. The mean values for hockey, basketball and soccer are 3.6m, 3.6m and 3m respectively (cf. Table 4.4).

To summarize, as seen in Table 4.4, in males (3.3m) and females (2.2m), the nearest upper body power score is found among the soccer players, whereas the farthest score in males (7.5m) is found among the rugby players and in females (5.6m), among the basketball players, which is also an outlier.

4.4.3 The T-test

Box plots illustrate the distributions of the T-test (cf. Figure 4.9) of athletes by gender and sport. Detailed descriptive statistics for this variable is presented in Table 4.4.

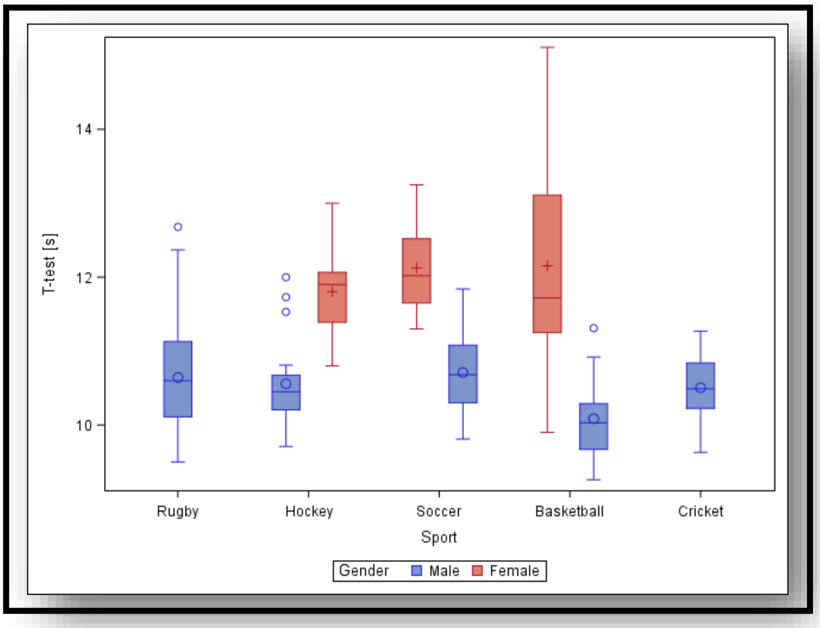

Figure 4.9: Box plot: T-test times of athletes, by gender and type of sport

As seen in Figure 4.9 (gender and sport considered separately), there is a narrow distribution among athletes of the specific sport, indicating that athletes partaking in the same sport tend to run at similar speeds. Overall (genders considered separately), the inter quartile of the T-test in males and females also overlap, indicating that there is no significant difference between the speed of athletes among the different sports. The mean T-test values for males in rugby, hockey, soccer, basketball and cricket were 10.64sec, 10.56sec, 10.71sec, 10.09sec and 10.51sec respectively (cf. Table 4.4). T-test scores for female hockey, soccer and basketball players were 11.81sec, 12.13sec, 12.15sec respectively (cf. Table 4.4).

In females, basketball is the only sport with a broader distribution, suggesting that basketball players mostly tend to run at different speeds among the players with a Q1 and Q2 value of 11.25sec and 13.11sec respectively. Furthermore, the lower quartile of the T-test of females in all the different sports are higher than the upper quartile of the T-test of the males, suggesting that in general, males tend to run faster than females. When gender is considered separately, Table 4.4 indicates overall mean T-test times for male and female athletes of 10.58sec (± 0.66sec) and 12.01sec (±0.87sec) respectively. Furthermore, the T-test time for men in basketball (10.09sec) was the fastest and soccer (10.71sec) the slowest. Rugby (10.64sec), hockey (10.56sec) and cricket (10.51sec) were very similar. However, as expected, the female athletes' mean T-test scores were much slower than that of their male counterparts. However, in female hockey (11.81sec) scored the fastest time and soccer (12.13sec) and basketball (12.15sec) the slowest.

4.4.4 The forty-meter sprint

Box plots illustrate the distributions of the forty-meter sprint (cf. Figure 4.10) of athletes by gender and sport. Detailed descriptive statistics for this variable is presented in Table 4.4.

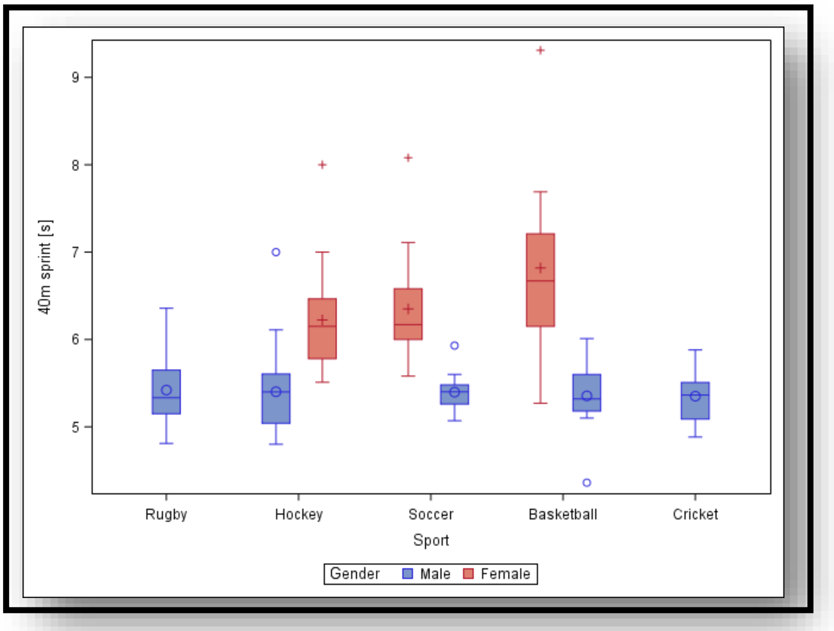

Figure 4.10: Box plot: Forty-meter sprint times of athletes, by gender and type of sport

As seen in Figure 4.10 (gender and sport considered separately), the results of the forty-meter sprint are very similar to the results of the T-test. Overall, there is a narrow distribution among athletes of the specific sport, indicating that athletes partaking in the same sport tend to run at similar speeds.

The inter quartile of the forty-meter sprint in males and females also overlap, indicating that there is no significant difference between the speed of athletes among the different sports. When stratified by gender, sports considered separately, the mean forty-meter sprint times for males in rugby, hockey, soccer, basketball and cricket were 5.42sec, 5.4sec, 5.4sec, 5.35sec and 5.35sec respectively (cf. Table 4.4). The forty-meter sprint times for females were, as expected, much slower for hockey, soccer and basketball, with mean values of 6.22sec, 6.35sec and 6.82sec respectively (cf. Table 4.4). Furthermore, basketball is the only "female" sport with a broader distribution, suggesting that basketball athletes tend to run at different speeds among the players with a Q1 and Q2 value of 6.15sec and 7.21sec respectively.

Furthermore, the lower quartile of the forty-meter sprint of the females in all the different sports are higher than the upper quartile of the forty-meter sprint times of the males, suggesting that, in general, males tend to run faster than females. Table 4.4 reveals overall mean forty-meter sprint times for male and female athletes of 5.4sec (±0.38sec) and 6.44sec (±0.74sec) respectively. When the sports were considered separately, the male basketball (5.35sec) and cricket players (5.35sec) presented the fastest mean forty-meter sprint time, while rugby (5.42sec) players presented the slowest. On the other hand, female basketball (6.82sec) players were the slowest and the hockey (6.22sec) players the fastest.

Table 4.4: Descriptive statistics for performance variables: Overall, by gender, by type of sport and for each combination of gender and type of sport

Variable	Statistic	All Sports			Rugby	Hockey		Soccer		Basketball		Cricket
		All	**F**	**M**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**M**
Forty-meter [sec]	**N**	**177**	**52**	**125**	**61**	**20**	**20**	**17**	**19**	**15**	**9**	**16**
	Mean	5.70	6.44	5.40	5.42	6.22	5.40	6.35	5.40	6.82	5.35	5.35
	Std	0.70	0.74	0.38	0.38	0.60	0.51	0.60	0.20	0.93	0.49	0.27
	Min	4.36	5.27	4.36	4.81	5.51	4.80	5.58	5.07	5.27	4.36	4.88
	Q1	5.24	5.99	5.14	5.15	5.78	5.04	6.00	5.26	6.15	5.18	5.09
	Median	5.50	6.28	5.36	5.33	6.15	5.40	6.17	5.40	6.67	5.32	5.36
	Q3	6.01	6.79	5.59	5.65	6.47	5.61	6.58	5.48	7.21	5.60	5.51
	Max	9.31	9.31	7.00	6.36	8.00	7.00	8.08	5.93	9.31	6.01	5.88
T-test [sec]												
	Mean	11.00	12.01	10.58	10.64	11.81	10.56	12.13	10.71	12.15	10.09	10.51
	Std	0.97	0.87	0.66	0.74	0.58	0.59	0.59	0.53	1.34	0.68	0.44
	Min	9.26	9.90	9.26	9.50	10.80	9.71	11.30	9.81	9.90	9.26	9.63
	Q1	10.29	11.51	10.15	10.11	11.39	10.21	11.65	10.30	11.25	9.67	10.23
	Median	10.81	11.96	10.50	10.60	11.90	10.45	12.02	10.68	11.72	10.03	10.49
	Q3	11.53	12.50	11.01	11.13	12.07	10.68	12.52	11.08	13.11	10.29	10.84
	Max	15.11	15.11	12.68	12.68	13.00	12.00	13.25	11.84	15.11	11.31	11.27
Vertical Jump [cm]												
	Mean	52.75	41.33	57.50	58.98	45.15	56.90	38.65	56.79	39.27	56.89	53.75
	Std	10.80	8.27	7.75	8.13	5.93	7.38	5.56	5.29	11.49	9.32	7.59
	Min	26.00	26.00	40.00	40.00	34.00	44.00	26.00	46.00	29.00	45.00	41.00
	Q1	45.00	36.00	52.00	55.00	41.00	51.50	36.00	53.00	32.00	48.00	48.50
	Median	55.00	40.00	58.00	59.00	45.50	58.00	39.00	58.00	37.00	58.00	55.00
	Q3	60.00	45.00	62.00	64.00	48.50	61.00	40.00	60.00	42.00	60.00	58.50
	Max	77.00	77.00	76.00	75.00	58.00	75.00	52.00	68.00	77.00	76.00	69.00

Medicine Ball Chest Throw [m]													
	Mean	4.69	3.42	5.22	5.53	3.64	4.95	3.00	4.12		3.59	5.11	5.76
	Std	1.19	0.65	0.94	0.96	0.56	0.49	0.41	0.61		0.77	0.49	0.58
	Min	2.20	2.20	3.30	3.80	2.85	4.30	2.20	3.30		2.50	4.40	5.10
	Q1	3.70	3.00	4.50	4.65	3.20	4.60	2.70	3.70		3.00	4.70	5.35
	Median	4.60	3.30	5.15	5.60	3.52	4.85	3.00	4.00		3.60	5.08	5.55
	Q3	5.60	3.74	5.90	6.20	4.10	5.45	3.20	4.40		3.90	5.50	6.10
	Max	7.50	5.60	7.50	7.50	4.60	5.80	3.63	5.80		5.60	5.80	7.20

Table 4.5: Correlation between the DLLT and performance tests, by gender and type of sport
(Table continues on next page...)

				Performance Test			
Gender	**Sport**	**N**	**Statistic**	**T-test**	**Forty-meter Sprint**	**Vertical Jump**	**Chest Throw**
All	**All**	**177**	**Pearson Correlation**	-0.16581	-0.18415	0.27759	0.24787
			P value	0.0274	0.0141	0.0002	0.0009
	Rugby	**61**	**Pearson Correlation**	-0.16404	-0.10705	0.26430	0.15313
			P value	0.2065	0.4115	0.0396	0.2387
	Hockey	**40**	**Pearson Correlation**	0.20335	0.12839	-0.04560	0.01423
			P value	0.2082	0.4298	0.7799	0.9306
	Soccer	**36**	**Pearson Correlation**	-0.13736	-0.22535	0.30737	0.28921
			P value	0.4244	0.1864	0.0682	0.0871
	Basketball	**24**	**Pearson Correlation**	-0.45289	-0.46928	0.74720	0.63947
			P value	0.0263	0.0207	<0.0001	0.0008
	Cricket	**16**	**Pearson Correlation**	0.04660	0.27594	-0.50784	0.46200
			P value	0.8639	0.3009	0.0446	0.0716
Female	**All**	**52**	**Pearson Correlation**	-0.39597	-0.43883	0.66634	0.52968
			P value	0.0037	0.0011	<0.0001	<0.0001
	Hockey	**20**	**Pearson Correlation**	-0.35675	-0.30257	0.40520	0.43454
			P value	0.1226	0.1947	0.0763	0.0555
	Soccer	**17**	**Pearson Correlation**	-0.26967	-0.23724	0.32149	0.19707
			P value	0.2952	0.3592	0.2083	0.4484

	Basketball	**15**	**Pearson Correlation**	-0.41610	-0.52918	0.87266	0.75675
			P value	0.1229	0.0425	<0.0001	0.0011
Male	**All**	**125**	**Pearson Correlation**	0.02049	0.06419	0.11100	0.15590
			P value	0.8206	0.4769	0.2178	0.0825
	Rugby	**61**	**Pearson Correlation**	-0.16404	-0.10705	0.26430	0.15313
			P value	0.2065	0.4115	0.0396	0.2387
	Hockey	**20**	**Pearson Correlation**	0.36411	0.26109	0.03769	0.37343
			P value	0.1145	0.2662	0.8746	0.1048
	Soccer	**19**	**Pearson Correlation**	0.57879	0.57831	-0.17324	-0.01163
			P value	0.0094	0.0095	0.4782	0.9623
	Basketball	**9**	**Pearson Correlation**	-0.39216	-0.09432	0.60037	0.59162
			P value	0.2965	0.8093	0.0874	0.0933
	Cricket	**16**	**Pearson Correlation**	0.04660	0.27594	-0.50784	0.46200
			P value	0.8639	0.3009	0.0446	0.0716

4.5 CORRELATION BETWEEN CORE STABILITY AND PERFORMANCE VARIABLES

The correlations of core stability (DLLT) with the performance tests, namely the T-test, the forty-meter sprint test, the vertical jump test and chest throw were calculated. The Pearson correlation coefficient and associated P-value are reported below.

Table 4.5 shows that, overall (both genders and all sports), core stability (DLLT) has a negative correlation with the T-test (r=-0.17) and forty-meter sprint (r=-0.18) and a positive correlation with the vertical jump (r=0.28) and chest throw (r=0.25). All these correlations are small (r< 0.3), but statistically significant (p<0.05). When stratified by gender, the following was observed: Overall, in females, core stability (DLLT) negatively correlated with the T-test (r=-0.40) and forty-meter sprint (r=-0.44) and positively correlated with the vertical jump (r=0.67) and chest throw (r=0.53). All these correlations are statistically significant (p<0.05), with a moderate correlation to the T-test and forty-meter sprint and a large correlation to the vertical jump and chest throw. Overall, in males, core stability (DLLT) has positive correlation with the T-test (r=0.02), forty-meter sprint (r=0.06), vertical jump (r=0.11) and chest throw (r=0.16). All these correlations are small (r<0.2), but not statistically significant (p>0.05). However, closer analysis of the data by type of sport and gender reveals some differences between these groups:

- **Rugby** (only male participants): Core stability (DLLT) negatively correlated with the T-test (r=-0.16) and forty-meter sprint (r=-0.11) and positively correlated with the vertical jump (r=0.26) and chest throw (r=0.15). All these correlations are small (r<0.3), very similar to the correlations observed in the total sample, but not statistically significant (p>0.05) (with the exception of the correlation with the vertical jump (p=0.0396)), possibly due to the reduced sample size.
- **Hockey**: Overall, both genders considered, core stability (DLLT) negatively correlated with the vertical jump (r=-0.05) and positively correlated with the T-test (r=0.20), forty-meter sprint (r=0.13) and chest throw (r=0.01). All these correlations are small (r<0.3), with a very small correlation with the vertical jump and chest throw (r=<0.1), but not statistically significant (p>0.05). When stratified by gender, the following was observed: In females, core stability (DLLT) is negatively correlated with the T-test (r=-0.36) and forty-meter sprint (r=-0.30) and positively correlated with the vertical jump

(r=0.41) and chest throw (r=0.43). All these correlations are moderate (r= 0.3-0.5), but not statistically significant (p>0.05).

In male hockey players, core stability (DLLT) is positively correlated with the T-test (r=0.36), forty-meter sprint (r=0.26), vertical jump (r=0.04) and chest throw (r=0.37). All these correlations are moderate (r= 0.3-0.5), with a small correlation with the forty-meter sprint and very small correlation with the vertical jump (r<0.1), but not statistically significant (p>0.05).

- **Soccer**: Overall, both genders considered, core stability (DLLT) is negatively correlated with the T-test (r=-0.14) and forty-meter sprint (r=-0.23) and positively correlated with the vertical jump (r=0.31) and chest throw (r=0.29). All these correlations are small (r<0.3), very similar to the correlations observed in the total sample, but not statistically significant (p>0.05) (with the exception of the moderate correlation with the vertical jump (r=0.3-0.5)). When stratified by gender, the results reveal the following: In female soccer players, core stability (DLLT) is negatively correlated with the T-test (r=-0.27) and forty-meter sprint (r=-0.24) and positively correlated with vertical jump (r=0.32) and chest throw (r=0.20). All these correlations are small (r<0.3), very similar to the correlations observed in the total sample, but not statistically significant (p>0.05) (with the exception of the moderate correlation with the vertical jump (r=0.3-0.5)). In male soccer players, core stability (DLLT) is negatively correlated with the vertical jump (r=-0.17) and chest throw (r=-0.01) and positively correlated with the T-test (r=0.58) and forty-meter sprint (r=0.58). The negative correlations are small (r<0.3), with a very small correlation with the chest throw (r<0.1), but not statistically significant (p>0.05). The positive correlations are large (r=0.5-0.7) and statistically significant (p<0.05).
- **Basketball**: Overall, both genders considered, core stability (DLLT) is negatively correlated with the T-test (r=-0.45) and forty-meter sprint (r=-0.47) and positively correlated with the vertical jump (r=0.75) and chest throw (r=0.64). The positive correlations are large (r=0.5-0.7) and very large (r=0.7-0.9), while the negative correlation is moderate (r=0.3-0.5), but all statistically significant (p<0.05). When stratified by gender, the picture looks similar: In female basketball players, core stability (DLLT) is negatively correlated with the T-test (r=-0.42) and forty-meter sprint (r=-0.53) and positively correlated with the vertical jump (r=0.87) and chest throw (r=0.76). The positive correlations are very large (r=0.7-0.9) and statistically significant (p<0.05), while a statistically large correlation exist with the forty-meter sprint (r=0.5-0.7) (p<0.05) and a moderate correlation with the T-test (r=0.3-0.5), but not

statistically significant (p>0.05). In male basketball players, core stability (DLLT) is negatively correlated with the T-test (r=-0.39) and forty-meter sprint (r=-0.09) and positively correlated with the vertical jump (r=0.60) and chest throw (r=0.59). The positive correlations are large (r=0.5-0.7), similar to the correlations of the overall basketball sample, but not statistically significant (p>0.05). The negative correlations are small (r<0.3) with a very small correlation (r<0.1) with the forty-meter sprint, but not statistically significant (p>0.05).

- **Cricket** (only male participants): Overall, core stability (DLLT) is negatively correlated with the vertical jump (r=-0.51) and positively correlated with the T-test (r=0.05), forty-meter sprint (r=0.28) and chest throw (r=0.46). A large correlation was observed with the vertical jump (r=0.5-0.7), a moderate correlation with the chest throw (r=0.3-0.5), a small correlation with the forty-meter sprint (r<0.3) and a very small correlation with the T-test (r<0.1). With the exception of the vertical jump (p=0.0446), these correlations were not statistically significant (p>0.5).

Table 4.6 Correlation between body fat percentage and performance tests by gender and type of sport (Table continues on next page...)

				Performance Test				
Gender	**Sport**	**N**	**Statistics**	**DLLT**	**T-test**	**Forty-meter Sprint**	**Vertical Jump**	**Chest Throw**
All	**All**	**177**	**Pearson Correlation**	-0.16873	0.66561	0.74108	-0.68766	-0.44219
			P value	0.0248	<0.0001	<0.0001	<0.0001	<0.0001
	Rugby	**61**	**Pearson Correlation**	-0.16161	0.38287	0.60897	-0.56104	-0.19106
			P value	0.2134	0.0023	<0.0001	<0.0001	0.1402
	Hockey	**40**	**Pearson Correlation**	0.22148	0.58532	0.59412	-0.56415	-0.50631
			P value	0.1696	<0.0001	<0.0001	0.0001	0.0009
	Soccer	**36**	**Pearson Correlation**	-0.29956	0.73401	0.84833	-0.80558	-0.53936
			P value	0.0759	<0.0001	<0.0001	<0.0001	0.0007
	Basketball	**24**	**Pearson Correlation**	-0.42601	0.78552	0.81873	-0.65321	-0.48874
			P value	0.0379	<0.0001	<0.0001	0.0005	0.0154
	Cricket	**16**	**Pearson Correlation**	0.44629	0.50942	0.38005	-0.64127	0.18816
			P value	0.0831	0.0438	0.1465	0.0074	0.4853
Females	**All**	**52**	**Pearson Correlation**	-0.206004	0.55104	0.60909	-0.46377	-0.17956
			P value	0.1428	<0.0001	<0.0001	0.0005	0.2028
	Hockey	**20**	**Pearson Correlation**	0.29330	-0.05200	0.25754	-0.08056	0.11252
			P value	0.2095	0.8276	0.2730	0.7356	0.6367
	Soccer	**17**	**Pearson Correlation**	0.10167	0.42623	0.76920	-0.54995	-0.07296
			P value	0.6978	0.0880	0.0003	0.0222	0.7808
	Basketball	**15**	**Pearson Correlation**	-0.038964	0.74627	0.76867	-0.43680	-0.08534
			P value	0.1511	0.0014	0.0008	0.1035	0.7623
Males	**All**	**125**	**Pearson Correlation**	-0.08054	0.29579	0.46364	-0.43162	0.09445
			P value	0.3719	0.0008	<0.0001	<0.0001	0.2948
	Rugby	**61**	**Pearson Correlation**	-0.16161	0.38287	0.60897	-0.56104	-0.19106
			P value	0.2134	0.0023	<0.0001	<0.0001	0.1402
	Hockey	**20**	**Pearson Correlation**	-0.22475	0.35506	0.37725	-0.28284	0.00293
			P value	0.3408	0.1245	0.1011	0.2269	0.9902
	Soccer	**19**	**Pearson Correlation**	-0.09664	-0.26649	-0.16165	0.21519	0.71756
			P value	0.6939	0.2701	0.5085	0.3763	0.0005

	Basketball	**9**	**Pearson Correlation**	-0.28105	0.32768	0.53935	-0.56320	-0.32178
			P value	0.4638	0.3893	0.1340	0.1143	0.3984
	Cricket	**16**	**Pearson Correlation**	0.44629	0.50942	0.38005	-0.64127	0.18816
			P value	0.0831	0.0438	0.1465	0.0074	0.4853

4.6 CORRELATION OF BODY FAT WITH PERFORMANCE VARIABLES

The correlations of the body fat percentage of the athletes with the performance variables, namely the DLLT, the vertical jump the T-test, the forty-meter sprint test and chest throw test were calculated. The Pearson correlation coefficient and associated P-value are reported below.

Table 4.6 displays that overall (both genders and all sports), fat percentage is negatively correlated with the DLLT ($r=-0.17$), vertical jump ($r=-0.69$) and chest throw ($r=-0.44$) and positively correlated with the T-test ($r=0.67$) and forty-meter sprint (0.74). All these correlations are large ($r=0.5-0.7$) and statistically significant ($p<0.05$) (with exception of the moderate correlation with the chest throw ($r=0.3-0.5$) and the small correlation with the DLLT ($r<0.3$), although statistically significant ($p<0.05$)). When stratified by gender, the following was observed: Overall, in females, fat percentage is negatively correlated with the chest throw ($r=-0.18$), vertical jump ($r=-0.46$) and DLLT ($r=-0.21$) and positively correlated with the T-test ($r=0.55$) and forty-meter sprint ($r=0.61$). The correlation with the DLLT as well as the chest throw is small, but not significant ($p>0.05$), while the correlation with the vertical jump is moderate ($r=0.3-0.5$) and statistically significant ($p<0.05$). Furthermore, the correlation with the T-test as well as the forty-meter sprint is large ($r=0.5-0.7$) and highly statistically significant ($p<0.0001$). Overall, in males, core stability negatively correlates with the vertical jump ($r=0.43$) and DLLT ($r=-0.08$) and positively correlates with the T-test ($r=0.30$), forty-meter sprint ($r=0.46$) and chest throw ($r=0.09$). The correlation with the forty-meter sprint and vertical jump is moderate ($r=0.3-0.5$) and statistically significant, while a statistically significant ($p<0.05$) small correlation was observed with the T-test ($r=0.1-0.3$). Furthermore, a very small correlation with the DLLT and chest throw is observed, but not statistically significant ($p>0.05$). However, closer analysis of the data by type of sport and gender reveals some differences between these groups:

- **Rugby** (only male participants): Body fat percentage is negatively correlated with the DLLT ($r=-0.16$), vertical jump ($r=-0.56$) and chest throw ($r=-0.19$) and positively correlated with the T-test ($r=0.38$) and forty-meter sprint ($r=0.61$). The forty-meter sprint and vertical jump show a large correlation ($r=0.5-0.7$) with body fat percentage that is highly statistically significant ($p=<0.0001$). The DLLT and chest throw display statistically insignificant ($p>0.05$) small ($r<0.3$) correlations with body fat percentage, while the T-test shows a statistically significant ($p<0.05$) moderate ($r=0.3-0.5$) correlation with body fat percentage.

- **Hockey**: Overall, both genders considered, body fat percentage is negatively correlated with the vertical jump ($r=-0.56$) and chest throw ($r=-0.50631$) and positively correlated with the DLLT ($r=0.22$), T-test ($r=0.59$) and forty-meter sprint ($r=0.59$). All the correlations are large ($r=0.5-0.7$) and statistically significant ($p<0.05$) (with the exception of the DLLT that indicates a small ($r<0.3$) correlation with body fat percentage ($p>0.05$)). When stratified by gender, the following was observed: In female hockey players, body fat percentage is negatively correlated with the T-test ($r=-0.05$) and vertical jump ($r=-0.08$) and positively correlated with the DLLT ($r=0.29$), forty-meter sprint ($r=0.26$) and chest throw ($r=0.11$). All these correlations are small ($r<0.3$), with a very small correlation ($r<0.1$) with the T-test and vertical jump and not statistically significant ($p>0.05$). In male hockey players, body fat percentage is negatively correlated with the DLLT ($r=-0.22$) and vertical jump ($r=-0.28$) and positively correlated with the T-test ($r=0.36$), forty-meter sprint ($r=0.38$) and chest throw ($r=0.00$). The T-test and forty-meter sprint show a moderate correlation ($r=0.3-0.5$), while the DLLT and vertical jump display a small ($r<0.3$) correlation and the chest throw a very small ($r<0.1$) correlation with body fat percentage. None of these correlations are statistically significant ($p>0.05$).
- **Soccer**: Overall, both genders considered, body fat percentage is negatively correlated to the DLLT ($r=-0.30$), vertical jump ($r=-0.81$) and chest throw ($r=-0.54$) and positively correlated to the T-test ($r=0.73$) and forty-meter sprint ($r=0.85$). All these correlations are very large ($r=0.7-0.9$) with statistical significance ($p<0.05$) (with the exception of the DLLT and chest throw that only indicates a small ($r<0.3$) ($p>0.05$) and large ($r=0.5-0.7$) ($p<0.05$) correlation with body fat percentage respectively). When stratified by gender, the results look different: In female soccer players, body fat percentage is negatively correlated with vertical jump ($r=-0.55$) and chest throw ($r=-0.07$) and positively correlated with DLLT ($r=0.10$), T-test ($r=0.43$) and forty-meter sprint ($r=0.77$). The forty-meter sprint displays a very large ($r=0.7-0.9$) correlation, while the vertical jump displays a large ($r=0.5-0.7$) correlation, the T-test a moderate correlation ($r=0.3-0.5$), the DLLT a small ($r<0.3$) correlation and the chest throw a very small ($r<0.1$) correlation with body fat percentage. All of these correlations are statistically insignificant ($p>0.5$) (with the exception of the correlation with the forty-meter sprint and vertical jump ($p<0.05$)). In male soccer players, body fat percentage is negatively

correlated with the DLLT (r=-0.10), T-test (r=-0.27) and forty-meter sprint (r=-0.16) and positively correlated with the vertical jump (r=0.22) and chest throw (r=0.72).
All these correlations are small (r<0.3), with a very small (r<0.1) correlation with the DLLT and also not statically significant (p>0.05) (with the exception of the correlation with the chest throw that indicates a very large (r=0.7-0.9) correlation with body fat percentage (p<0.05)).

- **Basketball**: Overall, both genders considered, body fat percentage is negatively correlated with the DLLT (r=-0.43), vertical jump (r=-0.65) and chest throw (r=-0.49) and positively correlated with the T-test (r=0.79) and forty-meter sprint (r=0.82). The forty-meter sprint and T-test very largely (r=0.7-0.9) correlate with body fat percentage, while there is a large correlation with the vertical jump (r=0.5-0.7) and a moderate (r=0.3-0.5) correlations with both the DLLT and chest throw. All the correlations are statistically significant (p<0.05). When stratified by gender, the following was found: In female basketball players, body fat percentage is negatively correlated with the DLLT (r=-0.04), vertical jump (r=-0.44) and chest throw (r=-0.09) and positively correlated to the T-test (r=0.75) and forty-meter sprint (r=0.77). The positive correlations are very large (r= 0.7-0.9) and statistically significant (p<0.05), while the negative correlations are very small (r<0.1) and not statistically significant (p>0.05) (with the exception of the moderate (r=0.3-0.5) correlation with the chest throw). In male basketball players, body fat percentage was also negatively correlated with the DLLT (r=-0.28), vertical jump (r=-0.56) and chest throw (r=-0.32) and positively correlated with the T-test (r=0.33) and forty-meter sprint (r=0.54). The forty-meter sprint and vertical jump show large correlations (r=0.5-0.7), while the DLLT, T-test and chest throw display moderate (r=0.3-0.5) correlations with body fat percentage; however, none of these correlations are statistically significant (p>0.5).
- **Cricket** (only male participants): Overall, body fat percentage is negatively correlated with the vertical jump (r=-0.64) and positively with the DLLT (r=0.45), T-test (r=0.51), forty-meter sprint (r=0.38) and chest throw (0.19). The T-test and vertical jump are largely (r=0.5-0.7) correlated with body fat percentage, while the DLLT and forty-meter sprint moderately (r=0.3-0.5) correlate with body fat percentage. Furthermore, the chest throw displays only a small (r<0.3) correlation with body fat percentage. All these correlations are statistically insignificant (p>0.05) (with the exception of the correlation with the T-test and vertical jump (p<0.05)).

4.7 MULTIPLE REGRESSIONS OF PERFORMANCE VARIABLES AGAINST CORE STABILITY AND ANTHROPOMETRIC MEASUREMENT

The main goal of the study was to investigate if core stability (DLLT) can predict athletic performance. In order to assess the effect of core stability on athletic performance, the variables measuring athletic performance (T-test, forty-meter sprint, vertical jump and chest throw; the dependent variables) were analysed using analysis of covariance (ANCOVA).

Since, apart from core stability (DLLT), the type of sport and the various anthropometric variables that potentially also affect athletic performance, the ANCOVA model for each dependent variable (T-test, forty-meter sprint, vertical jump and chest throw) included the following independent variables:

- Age, height, weight, BMI, fat%, fat%^{2}, sport, gender, DLLT;
- The two variable interactions: sport x gender, sport x DLLT, gender x DLLT; and
- The three-variable interaction: sport x gender x DLLT.

Fitting the above interaction terms allowed for the DLLT regression slopes to differ between genders and types of sport.

Using the collection of independent variables described above, backward model selection was performed as follows: starting with the full model fitting all the above variables, at each selection step that variable was chosen for exclusion from the model whose exclusion from the model achieved the largest increase in the Schwarz Bayesian Information Criterion (SBC). The SBC was chosen as model selection criterion because in our experience it generally led to the most parsimonious model (model with fewest variables), thus reducing the potential of model over-fit. At all stages during the backward selection process, model hierarchy was observed, namely a lower order term could leave the model only if there were no higher order interaction terms in the model that contained the lower order term.

For each measurement of athletic performance, the final model selected by the SBC is reported here, together with estimates of the regression slopes associated with the variable DLLT (core stability) from the final selected model.

The SAS procedures GLM and GLMSELECT were used to fit the ANCOVA models and perform model selection respectively.

Table 4.7: T-test: ANCOVA (Final Selected Model)

Variable	DF	F statistic	P-value
BMI	1	18.55	<0.0001
Fat Percentage	1	0.20	0.6593
Fat percentage^2	1	7.36	0.0074
Sport	4	3.20	0.0145
DLLT	1	4.12	0.0440
Gender	1	20.65	<0.0001
DLLT*Gender	1	6.09	0.0146
Gender*Sport	2	4.97	0.0081

Table 4.7 shows that of the anthropometric measurements, BMI and fat percentage (quadratic term) are significant predictors of the T-test. Of the demographic variables, gender, type of sport and the gender x sport interaction are significant.

Core stability is a significant predictor of performance in the T test; specifically, the effect of core stability is gender specific, as suggested by the inclusion of the DLLT x Gender interaction in the final selected model. The regression slope of T-test against DLLT in females is -0.02323010 and in males 0.00228054 (cf. Table 4.11).

Table 4.8: Forty-meter sprint: ANCOVA (Final Selected Model)

Variable	DF	F statistic	P-value
Length	1	6.06	0.0149
Weight	1	10.14	0.0017
Fat Percentage	1	0.02	0.8854
Fat percentage2	1	17.37	<0.0001
DLLT	1	9.34	0.0026
Gender	1	32.20	<0.0001
DLLT*Gender	1	16.34	<0.0001
Gender*Sport	6	4.76	0.0002

Table 4.8 shows that of the anthropometric measurements, length, weight and fat percentage predict forty-meter sprint. Of the demographic variables, gender and the gender x sport interaction.

Core stability is a significant predictor of performance in the forty-meter sprint; specifically, the effect of core stability is gender specific, as suggested by the inclusion of the DLLT x Gender interaction in the final selected model. The regression slope of forty-meter sprint against DLLT in females is -0.02234547 and in males 0.00313233 (cf. Table 4.11).

Table 4.9: Vertical jump: ANCOVA (Final Selected Model)

Variable	DF	F statistic	P-value
Length	1	7.11	0.0084
BMI	1	18.65	<0.0001
Fat Percentage	1	59.97	<0.0001
DLLT	1	14.05	0.0002
Gender	1	13.17	0.0004
DLLT*Gender	1	9.20	0.0028
DLLT*Sport	4	3.11	0.0167

Table 4.9 shows that of the anthropometric measurements, length, BMI and fat percentage predict Vertical Jump. Of the demographic variables, gender interaction.

Core stability is a significant predictor of performance in the vertical jump test; specifically, the effect of core stability is gender and sport specific, as suggested by the inclusion of the DLLT x Gender and DLLT x Sport interactions in the final, selected model. The regression slope of Vertical Jump against DLLT in females is 0.35246964 and in males 0.01977723 (cf. Table 4.11).

Table 4.10: Medicine ball chest throw: ANCOVA (Final Selected Model)

Variable	DF	F statistic	P-value
Weight	1	385.91	<0.0001
Fat Percentage	1	163.25	<0.0001
Sport	4	14.48	<0.0001
DLLT	1	10.22	0.0017

Table 4.10 shows that of the anthropometric measurements, weight and fat percentage predict chest throw. Of the demographic variables, sport is the only significant predictor.

Core stability is a significant predictor and the relationship of core stability is not gender or sport specific, as suggested in the final, selected model. The common regression slope of chest throw against DLLT for both males and females is 0.00989082 (cf. Table 4.11).

Table 4.11: Effect of core stability (DLLT) on athletic performance: Regression slopes of DLLT from ANCOVA model

Test	Gender	Slope Estimate	Standard Error	T value	P-value
T-test	Female	-0.02323010	0.00908858	-2.56	0.0115
	Male	0.00228054	0.00490952	0.46	0.6429
Forty-meter Sprint	Female	-0.02234547	0.00554872	-4.03	<0.0001
	Male	0.00313233	0.00297324	1.05	0.2937
Vertical Jump	Female	0.35246964	0.09006799	3.91	0.0001
	Male	0.01977723	0.05322496	0.37	0.7107
Chest Throw	Male and female	0.00989082	0.00309335	3.20	0.0017

CHAPTER 5

DISCUSSION OF RESULTS

5.1 INTRODUCTION

This chapter will interpret and discuss the different performance measures obtained through testing, as well as the correlation between the performance variables and the DLLT.

Core stability training is an important aspect of athletic training and as previously indicated, core stability can possibly enhance athletic performance and also prevent the risk of injury. In theory, it is known that core stability and athletic performance are interrelated; yet the current literature does not fully support this relationship. The purpose of a study conducted by Sharrock *et al*. (2011:71), was to observe the relationship between core stability and athletic performance among university athletes.

The DLLT was used to measure core strength, which served as the test for core stability, while athletic performance was quantified doing the forty-meter sprint, T-test, vertical jump and medicine ball chest throw. Speed, power and agility are all important attributes required in many sports and therefore, the previously mentioned tests were selected in order to predict performance ability during the actual game or match of rugby, hockey, soccer, basketball and cricket. The results of this study provide evidence with regards to the relationship between core stability and athletic performance. Our present understanding of core stability is limited to some degree and should be enhanced, in order to develop effective training programmes, to improve athletic performance.

The sample included fifty-two (n=52) female and hundred and twenty-five male athletes (n=125) participating in rugby (n=61), hockey (n=20), soccer (n=19), basketball (n=9) and cricket (n=16).

5.2 ANTHROPOMETRIC RESULTS

A well-conditioned athlete is expected to have attributes such as endurance, speed, agility, power, flexibility and sport-specific skills. Coupled with these characteristics, athletes competing at an elite competition level need to have certain morphological attributes depending on their playing position. Within a team, these characteristics may vary considerably, making team sports unusual, although the players within a team are generally fairly similar in their characteristics. It is well known that the analysis of body composition is an essential component to improve sport performance in elite athletes (Durandt *et al.,* 2006:38). Although some degree of body fat serves as an energy source during activity, it serves as extra weight that does not contribute to the generation of muscle power and therefore will detract from sprinting or jumping ability, decreasing sport performance. It is therefore very important to maintain an optimal body fat percentage. The mean body fat percentage in this study (both genders and all sports) was 14.04 ±6.69%. The anthropometric profiles of the athletes participating in this research project were similar to elite standards (Bruso, 2017:online).

The results further revealed that a statistically significant performance improvement in all tests are identified when body fat percentage of the athletes decrease ($p<0.0001$) ($r>0.5$), (however, just a moderate improvement in the performance of the chest throw ($r=-0.44$) ($p=<0.0001$) and a small improvement in the performance of the DLLT ($r<0.17$) ($p=0.0248$) were found).

Furthermore, when stratified by gender, average body masses of 79.07kg ± 15.03kg and 61.34kg ± 12.02kg and fat percentages of 11.25% ± 4.6% and 20.76% ± 6.47% were reported for male and female athletes respectively. These results are similar to the 6-13% and 14-20% reported for elite male and female athletes respectively (Haff & Triplett, 2016:316). Overall, stratified by gender, the agility T-test ($r=0.55$) and forty-meter sprint ($r=0.61$) among females display statistically significant large performance improvements when the body fat percentage decreases ($p<0.0001$), while the vertical jump displays a statistically significant moderate performance improvement when the body fat percentage decreases ($r=-0.46$) ($p=0.0005$). Furthermore, the DLLT ($r=-0.21$) and chest throw ($r=0.18$) display a small performance improvement when body fat percentage decreases, but are not statistically significant ($p>0.05$). In male athletes, the T-test ($r=0.30$), forty-meter sprint ($r=0.46$) and vertical jump ($r=-0.43$) display a statistically significant moderate performance improvement when the body fat percentage decreases ($p<0.05$), while the DLLT reveals a very small insignificant performance improvement when the body fat percentage decreases. None of the other performance tests indicated any statistically significant large improvements in performance when the body fat percentage decreases ($p>0.05$). The body fat percentage of athletes were also calculated among the different sport codes:

- **Rugby** (only male participants) - The mean body fat percentage of 11.9% is within the range of 14.3 ±2.7% for junior South African rugby players (Durandt *et al.,* 2006:41). The results display - as expected - statistically significant large improvements in both the forty-meter sprint ($r=0.61$) and vertical jump ($r=-0.56$) performance tests when the body fat percentage decreases ($p<0.0001$).
  The T-test also shows a statistically significant increase in performance when the body fat percentage decreases. However, the improvement is only moderate ($r=0.38$) ($p=0.0023$). None of the other performance tests show any statistically significant large performance improvements when the body fat percentage decreases ($p>0.05$). Rugby is a sport that requires numerous stops, turns, jumping, throwing and sprinting. The sprinting and jumping components are two aspects in rugby that benefit most from an optimal body fat percentage. The lighter the player, the easier it will be to jump in the air or sprint from the one side of the field to the other. As found, the contact events such as rucks, tackles and passes are not so much dependent on the body fat percentage of the player.
- **Hockey** – Overall, both genders considered, the majority of performance tests showed statistically significant large performance improvements when body fat percentage decreases ($r>0.5$) ($p<0.05$) (with the exception to the DLLT that display no significant, large performance improvement when body fat percentage decreases ($r=0.22$) ($p=0.1696$)). Hockey players cover a distance of nine kilometers per game (Fox, 2016:online). The game also requires running and shooting with a stick that require upper and lower body power and endurance. For both the abovementioned reasons, it is understandable that an optimal body fat percentage will benefit the athlete. When stratified by gender, the results look different: In female athletes, the results demonstrate that the mean body fat percentage of 18.16% ±3.59% is within the reported percentage ranges of 16.9% for elite hockey players (Mala *et al.*, 2015:210). However, it displays no statistically significant large effect on any of the performance measures in female athletes ($r<0.3$) ($p>0.05$). In male athletes, the mean body fat percentage was 11.11%, similar to published results of 12.24% ± 2.4% for elite hockey players (Duthie *et al.*, 2003:977). The male athletes revealed a moderate performance increase in both the forty-meter sprint ($r=0.38$) and T-test ($r=-0.36$) when the body fat percentage decreases, but not significant ($p>0.05$). None of the other tests revealed large performance differences when the body fat percentage decreases. This study used university athletes and it may possibly be that the level of play is lower than that of national athletes. Therefore, one can conclude that in higher levels of hockey,

players might benefit (performance based) from lower body fat percentages due to higher physical demands placed on the body of the player.

- **Soccer** – Overall, both genders considered, the majority of performance tests display a statistically significant improvement in performance when the body fat percentage decreases ($r>0.5$) ($p<0.05$) (with the exception to the DLLT that only reveal a small performance improvement when body fat percentage decrease ($r=-0.30$) ($p=0.1696$)). In soccer, players run ± eleven kilometers per game (Fox, 2016:online). It is therefore important to obtain minimal extra 'dead weight' in order to cover this distance with ease. When stratified by gender, the results look a bit different: In female athletes, the mean body fat percentage of 23.68% is within the norms of 19.53% ± 2.59% for elite soccer athletes (Mala *et al.*, 2015:210). The results display that the performance of the forty-meter sprint ($r=0.77$) ($p=0.0003$) and vertical jump ($r=-0.55$) ($p=0.0222$) increase significantly when body fat percentage decreases, while the T-test reveals a moderate ($r=0.43$) increase in performance when the body fat percentage decreases. The sprinting and jumping components are two aspects in soccer that benefit most from an optimal body fat percentage. The lighter the player, the easier it will be to jump in the air or sprint from the one side of the field to the other. None of the other performance tests show that body fat percentage has any significant effect on the athlete's performance. In male athletes, the mean body fat percentage was 8.71%, similar to published results of 10.15% ± 3.5% for elite soccer players (Kashani *et al.*, 2013:1186). The results display no large performance improvements in one of the performance tests when the body fat percentage decreases ($r<0.3$) ($p>0.05$). However, the results reveal a statistically significant large decrease in chest throw performance when the body fat percentage decreases ($r=0.72$) ($p=0.0005$)). It can be concluded that in higher levels of soccer, players might benefit (performance based) from lower body fat percentages due to higher physical demands placed on the body of the player.
- **Basketball** – Overall, both genders considered, all the tests displayed a statistically significant increase in performance when the body fat percentage decreases ($r>0.5$) ($p<0.05$); however, the improvements in the chest throw ($r=-0.49$) and DLLT ($r=-0.43$) are only moderate ($p<0.05$). Basketball is a sport that requires much power, speed and agility. A total distance of four kilometers is covered during a basketball match (Fox, 2016: online). This indicates the level of sprinting occurring on the course. The player should also be able to shoot many goals during the match. The sprinting and jumping

components are two aspects in basketball that benefit most from an optimal body fat percentage.

The lighter the player, the easier it will be to jump in the air or sprint from the one side of the court to the other. On the other hand, the throwing mechanism of the player is not so much dependent on the body fat percentage of the player. When stratified by gender, the results are as follows: In female athletes, the mean body fat percentage of 20.9% is within the norms of 21.22% ±1.66% for elite female basketball players (Mala *et al.*, 2015:210). The results display that for females, the T-test ($r=0.75$) and forty-meter sprint ($r=0.77$) times significantly improved when the body fat percentage decreases ($p<0.05$). There is also a moderate, but not statistically significant vertical jump performance improvement when the body fat percentage decreases ($r=-0.44$) ($p>0.05$). The DLLT ($r=0.04$) and chest throw ($r=-0.09$) displays no statistically significant large performance improvements when the body fat percentage decreases ($r=<0.1$) ($p>0.05$). In male athletes, the mean body fat percentage of 10.86% is within the norms of 10.9% for elite basketball players (Gerodimos *et al.*, 2005:115). The results display large performance improvements in both the forty-meter sprint ($r=0.54$) and vertical jump ($r=-0.56$) and a moderate performance increase in the T-test ($r=0.33$) and chest throw ($r=-0.32$), that are not statistically significant ($p>0.05$). The DLLT only displays a small performance improvement when the body fat percentage decreases ($r=-0.28$) but is not statistically significant ($p=0.4638$). As one can see, the running and jumping abilities of a basketball player are most affected by the body fat percentage of the player.

- **Cricket** (only male participants) - The mean body fat percentage of 12.03% is within the range of 10.62% ± 2.89% for elite cricket players (Koley, 2011:431). The results display a statistically significant large performance improvement in both the T-test ($r=0.51$) and vertical jump ($r=-0.64$) when the body fat percentage decreases ($p<0.05$). There is a moderate performance decrease of the DLLT ($r=0.45$) ($p=0.831$), while the performance of the forty-meter sprint improved moderately when the body fat percentage decreases ($r=0.38$) ($p=0.1465$). None of the other performance tests showed any statistical significant changes in performance ($p>0.05$). Cricket requires agility to run from the one side of the pitch, stopping and running in the other direction. Therefore, it may be expected that an optimal body fat percentage will benefit the athlete when completing these actions.

It is clear that body composition varies according to the type of sport and referring to the mentioned results, we can conclude that sports involving more running result in lower body fat percentages. As found in this study, body fat percentage plays a bigger role in sport performance in certain sports than other; nevertheless, it plays an important role in athletic performance and can contribute to either poor or significant results.

To conclude: Overall (both genders and all sports), the T-test, forty-meter sprint and vertical jump are the only performance measures that largely improve when the body fat percentage decreases, whereas the chest throw and DLLT are only moderately and slightly correlated to the body fat percentage of the athlete. When stratified by gender: In females, the vertical jump, T-test and forty-meter sprint are also the only three tests that indicate large performance improvements when the body fat percentage decreases, although the correlation with the vertical jump is only moderate. In males, the results look the same. However, the improvements of the forty-meter sprint and vertical jump are only moderate, while the performance improvement of the T-test is small.

5.3 ATHLETIC PERFORMANCE MEASURES

Many sports require that athletes be explosive at any given moment. Athletes are constantly transferring forces between the extremities and are in need of support from the musculature of the core to keep the kinetic chain of the body intact. Some authors believe that core stability improves sport performance. Through this research, these correlations are only small ($r<0.2$) in male athletes, similar to results found by Sharrock *et al*. (2011:70) and moderate to large ($r=0.3$-0.7) in female athletes, similar to results found by Nesser and Lee (2009:25). However, these findings contradict the results found by Sharrock *et al*. (2011:70) that only found small correlations between these variables in female athletes, except with the chest throw that showed significant correlations with the DLLT.

5.3.1 The vertical jump

Many sports such as rugby, basketball and soccer require explosive lower body power to change direction at a high speed or to jump from the ground to a maximum height (Sharrock *et al*., 2011:69). These high intensity, short bursts of sprinting and jumping demands high anaerobic capacity. This study used the vertical jump to determine lower body power.

Overall, gender considered separately, the mean vertical jump scores for male and female athletes were 57cm and 41cm respectively, which is lower than the reported vertical heights of 65cm and 47cm for competitive university male and female athletes respectively (Baechle & Earle, 2008:278). Reiman and Manske (2009:183-184), reported vertical jump scores of 61cm and 41cm for male and female athletes respectively - which is closer to the reported results, although still better. This can indicate that our athletes can work on their power ability in order to improve to a higher level of competition.

Furthermore, overall (both genders and all sports), the results only display a small improvement in performance when core stability (DLLT) increases ($r=0.28$) ($p=0.0002$). This is similar ($r=-0.17$) to results found by Sharrock, *et al*. (2011:70) and Nesser and Lee (2009:24), ($r=-0.29$); however, their correlations are insignificant ($p>0.05$) and indicate that improved core stability decreases athletic performance. Tse *et al*. (2005:550) also completed an eight-week core intervention program with college rowers and compared the results with a controlled group. According to this study there were no significant differences in performance between the two groups with pre- and post-test vertical jump values of 56 ±6cm and 55 ±6cm and 57 ±4cm and 57 ±5cm for the core and controlled group respectively.

When the sports were considered separately, overall, basketball ($r=0.75$) ($p=<0.0001$) and cricket ($r=-0.51$) ($p=0.0446$) are the only sports that display a large improvement in the vertical jump performance when core stability (DLLT) increases. However, as stated above, in cricket the correlation is negative, indicating a decrease in performance when core stability (DLLT) increases. These results are similar to those of a study done by Allah and Nagi (2013:online), who reported vertical jump performance values of 50.37 ±3.79cm with a negative correlation ($r=-0.07$) between the vertical jump and core stability. If we compare these correlations with each other, basketball demands a lot of jumping while cricket athletes do not necessarily jump that much during a match, except to maybe catch a flying ball. Therefore, they just might not be conditioned in this movement. Furthermore, soccer displays a moderate but not significant ($p=0.0682$) improvement in the vertical jump performance when core stability (DLLT) increases ($r=0.31$). None of the other sports display any statistically significant large correlations between these variables.

When stratified by gender: Overall, in females there is a statistically significant, large improvement in vertical jump performance when core stability (DLLT) increases ($r=0.67$) ($p<0.0001$).

Overall, in male athletes, the results display no statistically significant improvement in the height of the vertical jump when core stability (DLLT) increases ($r=0.11$) ($p=0.2178$). However, when the different sports were considered separately, in females, basketball is the only sport that displays a very large improvement in vertical height performance when core stability (DLLT) increases ($r=0.87$) ($p<0.0001$). Hockey ($r=0.41$) and soccer ($r=0.32$) display a moderate performance improvement, although not statistically significant ($p>0.5$). In males, overall, the results display an insignificant, small improvement in vertical jump performance when core stability (DLLT) increases ($r=0.11$) ($p=0.2178$). When the sports are considered separately, similarly to the overall sample, basketball ($r=0.60$) and cricket ($r=-0.51$) are the only sports that display a large correlation between core stability (DLLT) and the vertical jump. However, in cricket - although statistically significant ($p=0.0446$) - the correlation is negative ($r=-0.51$). This indicates that performance decreases when core stability (DLLT) increases. None of the other sports indicate any statistically significant large improvements in vertical jump performance when core stability increases.

5.3.2 The medicine ball chest throw

Because many sports entail a throwing or hitting mechanism, upper body power is another modality classified as important for athletic performance in various sports, such as rugby, hockey, basketball and cricket. This study used the chest throw as indicator to determine upper body power. Overall, gender considered separately, the mean overall chest throw score in this study was 5.20m and 3.40m for male and female athletes respectively. Reiman and Manske (2009:261), report college athlete shot put values of 2.88m for females and 3.72m values for high school boys. These results are also found in a seated position with a 4.5kg ball, while this study completed the chest throw in a kneeling position with a 5kg ball. The athletes were not allowed to fall forward, which required isometric control of the core musculature. Sell *et al.* (2015:156), also reported chest throw values of 2.65m ±0.7m and 2.80m ± 0.5m for competitive university female and male athletes respectively. The results of this study show that upper body power of males and females are above reported norms, although it should be taken into consideration that the position of the throw from the first-mentioned study differs from this study.

Furthermore, overall (both genders and all sports) the results display a statistically significant, although small chest throw performance improvement when core stability (DLLT) increases (r=0.25) (p=0.0009).

These results are different from results found by Allah and Nagi (2013:online), who reported a large correlation (r=0.57) between the chest throw and core stability. On the contrary, Sell *et al.* (2015:152), reported a significant, moderate decrease in chest throw performance when core stability (DLLT) increases (r=-0.39) (p=0.023). When the sports are considered separately, overall, basketball is the only sport that displays a statistically significant large chest throw performance improvement when core stability (DLLT) increases (r=0.64) (p=0.0008). This is similar (r=0.57) to results found by Allah and Nagi (2013:online). Cricket, on the other hand, displays a moderate chest throw performance improvement when core stability increases, although insignificant (r=0.46) (p=0.716). This contradicts the findings of Hilligan (2008:56), who reported significant improvements in the bowling speed of cricketers after completing a core stability programme (p<0.0001). When stratified by gender: Overall, in females, the chest throw performance revealed a significant large improvement when core stability (DLLT) increases (r=0.53) (p<0.0001). Sharrock *et al.* (2011:70), reported a negative correlation (r=-0.39) (p=0.23) between these variables, along with Sell *et al.* (2015:152) that also reported a significant negative correlation (r=-0.39, p=0.023) between core stability (DLLT) and the chest throw, indicating a decrease in performance when core stability (DLLT) increases. When the different sports were considered separately, basketball is the only sport that displays a statistically significant, large improvement in chest throw performance (r=0.76) (p=0.0011), while hockey shows a moderate increase in chest throw performance when core stability (DLLT) increases (r=0.43), but not insignificant (p=0.0555). None of the other sports showed any significant, large improvements in sport performance when core stability (DLLT) increases.

In male athletes, overall, there is only a small (r=0.16) improvement in chest throw performance when core stability (DLLT) increases, although not significant (p=0.825). This is different to the findings of Sharrock et al, (2011:70) who reported a moderate significant correlation although negative (r=-0.322) between these variables. When the different sports were considered separately, hockey (r=0.37) (p=0.1048) and cricket (r=0.46) p=0.0716) display a moderate improvement in chest throw performance when core stability (DLLT) increases, while basketball (r=0.59) (p=0.0933) shows a large improvement in chest throw performance when core stability (DLLT) increases. However, none of these correlations are significant.

5.3.3 The T-test

Enhanced change of direction and the ability to accelerate from a stationary stance to full speed is important in rugby, hockey, soccer, basketball and cricket. In terms of agility, the athletes of this study recorded mean T-test times of 10.58sec and 12.01sec for male and female athletes respectively**.** According to Haff and Triplett (2016:311), the time in seconds for competitive university athletes to complete the T-test is 11.92sec ± 0.52sec and 10.08 ±0.46sec for female and male athletes respectively. Reiman and Manske (2009:202), reported T-test values of 10 and 10.8seconds for competitive university male and female athletes respectively. Furthermore, Pauole *et al*. (2000:446), reported T-test values of 10.94sec ± 0.6sec and 9.94sec ± 0.5sec for competitive university female and male athletes respectively. The results are similar to the results of the study, which indicates that the agility of athletes is up to a good standard.

Furthermore, overall (both genders and all sports), the results display only a small significant improvement in the T-test performance when core stability (DLLT) increases (r=-0.17) (p=0.00.274). This correlation is similar to the results found by Sharrock *et al*. (2011:70), although they found that when core stability (DLLT) increases, the performance of the T-test decreases (r=0.05). When the sports were considered separately, overall, basketball is the only sport that displayed a moderate improvement in the T-test performance when core stability (DLLT) increases (r=-0.45) (p=0.0263). These results are similar to results reported by Allah and Nagi (2013:online), although they reported a very large decrease in the T-test performance when core stability increases (r=0.90). When stratified by gender: Overall, in female athletes, the results also display a significant moderate improvement in T-test performance when core stability (DLLT) increases (r=-0.40) (p=0.0037). When the sports were considered separately, hockey (r=-0.36) (p=0.1226) and basketball (r=-0.42) (p=0.1229) display the same results, but these correlations are insignificant (p>0.05).

In male athletes, overall, there is a very small decrease in T-test performance when core stability (DLLT) increases (r=0.02) (p=0.8206). When the sports were considered separately, hockey displayed an insignificant (p=0.1145) moderate (r=0.36) decrease in T-test performance when core stability (DLLT) increases, while soccer showed a significant large decrease in T-test performance when core stability (DLLT) increases (r=0.58) (p=0.0094). On the other hand, basketball displays an insignificant, moderate improvement in T-test performance when core stability (DLLT) increases (r=-0.39) (p=0.2965). None of the other sports displayed a significant, large improvement in T-test performance when core stability (DLLT) increases.

5.3.4 The forty-meter sprint

Many sport types entail fast pacing sprints; therefore, speed is required to excel at the highest levels. This study used the forty-meter sprint to determine the speed of the athlete and reported overall mean values of 5.40sec and 6.44sec for male and female athletes respectively. The mean values for university athletes for the forty-meter sprint are reported by Allah and Nagi (2013:online), as 6.11sec ±0.53sec. Steffen *et al*. (2007:599) also reported forty-meter sprint times of 5.97sec ±0.25sec and 5.93sec ±0.26sec for both an intervention and controlled group respectively.

Furthermore, overall (both genders and all sports), the results display only a significant, small forty-meter sprint performance improvement when core stability (DLLT) increases (r=-0.18) (p=0.0141). This is contradictory to the results of Sharrock, *et al*. (2011:70), (r=0.14) and Allah and Nagi (2013:online), (r=0.14) who found no statistically significant improvement in performance for both reported positive correlations, indicating a decrease in forty-meter sprint performance when core stability increased. Another study done by Tse *et al.* (2005:550), also reported no significant relationship (p> 0.05) between core stability and athletic performance after an 8-week core intervention program. On the other hand, Nesser and Lee (2009:24), reported a moderate although insignificant correlation between these variables (r=-0.37) (p=0.13). When the sports were considered separately, overall, basketball is the only sport that displays a significant moderate improvement in forty-meter sprint performance when core stability (DLLT) increases (r=-0.47) (p=0.0207). When stratified by gender: Overall, in females, there is also a significant moderate improvement in forty-meter sprint performance when core stability (DLLT) increases (r=-0.44) (p=0.0011). However, Sharrock *et al.* (2011:70), reported no significant, large correlation between these variables (r=-0.17) (p=0.0463). When the sports were considered separately, hockey (r=-0.30) (p=0.1947) displays an insignificant moderate improvement in forty-meter sprint performance when core stability (DLLT) increases, while basketball shows a significant, large improvement in forty-meter sprint performance when core stability (DLLT) increases (r=-0.53) (p=0.0425). Soccer revealed only an insignificant, small improvement in forty-meter sprint performance when core stability (DLLT) increases (r=-0.27) (p=0.2952).

In male athletes, overall, there is no improvement in the forty-meter sprint performance when core stability (DLLT) increases (r=0.06) (p=0.4769).

When the sports were considered separately, soccer is the only sport that reported a statistically significant, large improvement in the forty-meter sprint performance when core stability (DLLT) increases (r=0.58) (p=0.0095). None of the other sports revealed significant large improvements in the forty-meter sprint performance when core stability (DLLT) increase.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 INTRODUCTION

This chapter will discuss the trends in the analyzed data and conclude the findings of this study. It will also discuss further recommendations concerning core stability programmes and athletic performance.

6.2 SUMMARY

The question subsequently answered was if core stability and athletic performance are interrelated to each other. Answers to this question from this research study concluded that core stability plays a more significant role in certain sports than others.

To date, generalization has been the only means to support athletes in the sporting industry with regards to the effect of core stability training on athletic performance. Many different studies have been conducted on the correlation between core stability and athletic performance, but because of the different outcomes, insufficient knowledge was available for the development of prescribing training programmes that contribute to improved athletic performance. This present investigation shed light on the role of core stability and athletic performance, but because there are so many factors playing a role in athletic performance, to comprehend a thorough examination that can summarize the beneficial effects of core training on athletic performance, still remains a challenge. Firstly, since core training is mostly performed in combination with other training modalities, it makes it difficult to conclude that core is the ultimate mediator for better performance. Apart from insufficient knowledge with regard to the effect of core stability on athletic performance, measuring core stability is difficult, because there is no golden standard and it is also difficult to quantify core stability to sport specific movements. However, the results of this study may enlighten possible areas of uncertainties that may exist in the sporting environment among athletes and coaches.

Many conflicting studies exist that states that core stability training improves core endurance, but shows no effect on athletic performance. However, in some cases the opposite was also found. Core stability (DLLT) reflects weak correlations to many performance measures with only significant correlations within certain sport codes.

6.3 CONCLUSION

This study reveals that in the overall sample (both genders and all sports), all correlations between core stability (DLLT) and the performance tests were small ($r<0.3$). However, when the different sports were considered separately, for basketball players there were very large to large correlations between core stability (DLLT) and both the vertical jump ($r=0.75$) and chest throw ($r=0.64$).

When stratified by gender: In females, overall for all sports, there were large correlations between core stability (DLLT), the vertical jump ($r=0.67$) and chest throw ($r=0.53$). However, when the different sports were considered separately, in female athletes, for basketball players there were very large to large correlations between core stability (DLLT) the vertical jump ($r=0.87$), chest throw ($r=0.76$), forty-meter sprint ($r=-0.53$) and T-test ($r=-0.42$).

In males, overall for all sports, there were only small correlations between core stability (DLLT) and all the performance tests ($r<0.2$). However, when the different sports were considered separately in male athletes, for basketball players there were large correlations between core stability (DLLT), the vertical jump ($r=0.60$) and chest throw ($r=0.59$). Furthermore, for soccer players there were large correlations between core stability (DLLT) and both the forty-meter sprint ($r=0.58$) and T-test ($r=0.58$); however, these correlations suggest a decrease in performance with increasing core stability (DLLT), since they are positive. Cricket players also revealed a large correlation between core stability (DLLT) and vertical jump ($r=-0.51$); however, this correlation also suggest a decrease in performance with increasing core stability (DLLT), since it is negative.

The association between core stability (DLLT) and athletic performance appears to be weak in the overall sample, that is, when the factors gender and in particular type of sport are ignored; however, when correlations are considered separately for the two genders and for the various types of sport, some large and very large correlations between core stability (DLLT) and specific performance tests can be identified. Thus, basketball players show large and very large correlations between core stability (DLLT) and both the vertical jump and chest throw. This study can serve as the basis of future research on the role of core stability in optimal performance in different sports; to the results of such research assist coaches and athletes with the development of training guidelines that enhances athletes' performances. Ideally sport specific tests will be able to better define and to examine the correlation of core stability with performance.

Furthermore, when body fat percentage is considered it is clear that body composition varies according to the type of sport. Overall (both genders and all sports), the study suggests very large correlations between body fat percentage and the performance tests, T-test (r=0.67), forty-meter sprint (r=0.74) and vertical jump (r=-0.69). When the different sports were considered separately, the results look similar. However, hockey (r=-0.51) and soccer (r=-0.54) also show a significant, large correlation between the chest throw and body fat percentage ($p<0.05$). When stratified by gender: Overall, in females the results show large correlations between body fat percentage, the T-test (r=0.55) and forty-meter sprint (r=0.61), whereas, in males, these correlations are only moderate.

6.4 LIMITATIONS

The primary limitation of this study is the lack of golden standard to measure core stability. The DLLT used in this study measures core strength in the sagittal plane, but does not measure muscle endurance, proprioception or any other key multi-planar muscular thought to control the core.

The population of this study also might have impacted the results of the data, because athletes were measured different times of the season which could suggest that conditioning might have influenced the results. Another limitation is the motivational component of the athletes' performance - which was not measured and might have played a role in the outcomes of the tests; some athletes might have been more demotivated to perform than others.

6.5 PRACTICAL RECOMMENDATIONS

The data above provide answers to the questions concerning the correlation between core stability and athletic performance. It is recommended that future researchers should seek to identify a golden standard test or battery of tests that quantifies core stability as it pertains to athletic performance. Another factor to consider as well is, to examine the specific functions of the core such as endurance, strength and stability separately, to determine how important each of them are. Research should furthermore also focus on specific sports and actual sport performance outcomes such as points per game, goals scored etcetera, but also include maximal performances ideally linked to the activity of choice (for example ball speed or distance if related to throwing). It also would be beneficial to examine the relationship between core stability and additional sport performance tests.

CHAPTER 7

REFLECTING ON THE RESEARCH PROCESS

7.1 INTRODUCTION

"How do you eat an elephant? One bite at a time" – Desmond Tutu. Research - at the end of the day - is a long process requiring hours of preparation and planning, an analytical mind, a courageous spirit, knowing what your final destination should be and then to seek the facts to support the truth. It is the process to prove new findings either right or wrong. To explore new ways of doing. To provide new insight into the ways we experience daily events. To provide answers to questions we as professionals and scholars in our field of practice might come to ask. The research process is a long journey and is not possible without the help of others. You learn to ask if you do not know, nor understand. You stop numerous times, change several sentences, correct, re-write and start all over if you have to. In the process you learn more about your strengths and weaknesses. You learn about the things that get you demotivated and further develop the things you are good at. What I have learned is that perseverance through all the ups and downs is what helps you to reach your final destination.

Research also opens the opportunity for bigger and better ideas because one question leads to another. It gives us scientific knowledge and reveals to us what it takes to be a professional athlete, a trainer and a coach, so that we can clinically show the world the scientific approach to performance. Ultimately it makes us evidence-based practitioners. Even though your way of thinking sometimes differs from others, the research industry is the place where you as researcher can influence the greatest academic minds.

This research developed my character on so many levels. Although there were times that quitting felt like the only option, I continued to battle and got to the end of this project. I am utterly thankful to be finished and will look back at this journey as one that moulded me into an equipped Biokineticist, coach and researcher.

I did not only complete my degree, but gained a whole book of knowledge, made new friends, met new colleagues and I can confidently say that "this journey was worth every step".

7.2 THE JOURNEY TO THE TOPIC

As researcher and athlete, I came to realize that most athletes and trainers do not have a thorough understanding of why they do what they do. Why they perform certain exercises or how it will benefit them in the long run. Due to our hectic lifestyle, people intend to do the most with the time they have available. The same principle counts in the sport industry. When training, athletes spend time on exercises that change the game, exercises that actually improve their performance. This led me to start questioning the effect of certain exercises on athletic ability and how these exercises contribute to the athlete's performance. I started to read more about core stability and athletic performance because many athletes spend a lot of time training their core. Most research conducted was only performed on small intervention groups or sample sizes and also used various methods to measure core stability due to no golden standard available to quantify sport specific movements. Numerous researchers also used sport-specific measures such as speeds tests, agility tests, power tests and strength tests to quantify performance, but because there is no way to predict athletic performance in measures such as points per game, assists per game, etc., the thought behind these measures is that better performance in these measures might relate to increased performance (athletes that jump higher might score more goals in basketball). Many studies also found that core stability exercises decrease or prevent the risk of injury and also improve core stability endurance, but alternatively athletic performance stay the same. It never made sense to me why athletes spend hours of training on something that does not contribute to their performance. As a Biokineticist, athlete and supporter of various sports, the abovementioned encouraged me to pursue answers to athletes competing on higher levels of competition with regards to core stability and athletic performance. Furthermore, I decided to measure all first team, university athletes' athletic performances by means of a forty-meter sprint, vertical jump, chest throw and T-test and compare that with their core stability by means of a DLLT to see if there is any correlation between these variables.

Another fascination was how the correlations between these variables change from one sport to the other. All the different sports require different movements that can influence the results in that regard, but statistics could clear out that hesitation. The results between the genders can also differ. Therefore, the topic of core stability and athletic performance among university athletes concluded my questions about the correlation between these variables.

There are still many questions within the athletic and rehabilitation sector and through research we can hopefully provide further answers to trainers and athletes.

7.3 PEARLS OF EXPERIENCE

The first day of a two-year journey was quite exciting, but also scary at first. I was full of enthusiasm, knowing this was an opportunity to gather research information and to increase the knowledge of trainers. However, nothing in life worth having comes easy. This journey required long hours of writing, short hours of sleep and difficult hours of testing. What make this difficult journey worthwhile, is the people you meet and the relationships you build along the way. Due to all the different sport codes (rugby, hockey, soccer, basketball and cricket), the mission was to accommodate them all. To get suitable times to ensure proper testing but also to accommodate their periodization programmes. Trainers and coaches must also believe and support your idea in order to get the athletes to partake in testing to get significant results. Not everyone is always keen and willing, since coaches hold their plans, ideas and training methods very close. Thankfully, due to a great conditioning coach, Mr Kobus Caldo, the journey to recruit athletes to be tested was a smooth journey. He is in charge of the conditioning of Kovsie Sport athletes and he understood the meaning and effect that the study would have on training and athletic performance.

Consider the following when attempting to start a research project:

- Learn to write/type academically;
- Make sure you have back-ups of your latest work and also save on a regular basis;
- Do not use multiple computers or memory sticks because at the end of the day, you have no idea where you left off;
- Save the file with the date you last worked on it;
- If you get a panic attack – sit and start to write; and
- Understand statistics.

7.4 PERSONAL REMARKS

For me, this journey was at times stressful and exhausting, but what I have learned along the way I will not exchange these experiences for anything. I am thankful for my support

system along the way. My sister was my biggest supporter and helped me to work through this process. For that, I am truly thankful. My family and friends also came second on various occasions as a result of this project, but their support encouraged me to endure and complete my dissertation as quickly as possible. My study leader, Prof Derik Coetzee, also added irreplaceable value to my project. His knowledge and experience in the field is beyond exceptional. He helped me when I thought there was no way out and also encouraged me throughout the whole journey. I am privileged to have him, not only as a supervisor but also as a mentor.

Chrisna Francisco also played a major part in my project. Without her help and motivation, I would not have been able to reach the end. She helped me with all the technicalities of my study and also guided me through the whole writing and research process. She was also the one that made sure that I was on track and that I meet all my deadlines in time.

Then there was statistics, something I only know the basics about. Prof Robert Schall, the best statistician there is in the field. I needed someone to break statistics down to a level that is understandable and something that makes sense when you read it. I needed someone who understood my needs and also someone that can present statistics from all the data I have gathered. His interpretation, explanation and presentation of statistics is of the highest quality and although it seems like nothing makes sense in the beginning, he was there to guide me through the whole process. The data gathering procedure was a long walk, but thanks to Kobus Caldo and all the Biokinetic interns, I had the easiest journey. Kobus arranged all the testing dates for me and the interns were my right hand when conducting the data. If it were not for them, this study might have been extended for another year.

Lastly, this journey would not have been possible without my heavenly Father. He gave me the strength, mental and physical ability to continue when the days were long and it seemed that there was no end in sight. After this research, I realized how many different factors can all contribute to this topic and are full of ideas to expand this study. This encourages me to do further investigation.

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APPENDICES

APPENDIX A: BIOGRAPHICAL QUESTIONNAIRE

Personal information

1. Participant Number: ______ **2. Date:** ______

3. Age (years) ______

4. Gender: ______ **5. Sport:** ______

6.Position (if applicable) ______

7. Previous injuries:

☐ Yes ☐ No

8. If yes, state:

☐ Hamstring	☐ Knee	☐ Groin	☐ Shoulder	☐ Back
☐ Ankle	☐ Hand	☐ Elbow	☐ Calf	☐ Hip

9. Did you receive any treatment for injury within the last two months?

☐ Yes ☐ No

APPENDIX B
DATA COLLECTION SHEET

DATA COLLECTION SHEET

Participant Number:

Anthropometrical measurements

Body composition

Weight:		**Height:**	
	kg		cm

Circumferences

Waist		**Hip:**	
	cm		cm
Bicep flexed:	cm	**Bicep relaxed**	cm
Calf:	cm		

Breadths

Humerus:		**Femur**	
	cm		cm

Skinfolds

1st Measurement		**2nd Measurement**	
Triceps:	cm	**Triceps:**	cm
Sub scapulais:	cm	**Sub scapularis:**	cm
Supra Spinal:	cm	**Supra spinal:**	cm
Abdomen:	cm	**Abdomen:**	cm
Front thigh:	cm	**Front thigh:**	cm
Calf:	cm	**Calf:**	cm

Functional tests

1st Measurement		**2nd Measurement**		**3rd Measurement**	
DLL:	°	**DLL:**	°	**DLL:**	°
Vertical Jump:	cm	**Vertical Jump:**	cm	**Vertical Jump:**	cm
T-test:	sec	**T-test:**	sec	**T-test:**	sec
Chest throw:	m	**Chest throw:**	m	**Chest throw:**	m
forty-meter Sprint:	sec	**forty-meter Sprint:**	sec	**forty-meter Sprint:**	sec

INFORMATION DOCUMENT

CORE STABILITY AND ATHLETIC PERFORMANCE

I, Nelmaré Loubser, (a master's student in Biokinetics at the University of the Free State) will be conducting a research study concerning core stability and athletic performance.

This is a document requesting your participation in this research study. The aim of the study is to determine if better core stability relates to better athletic performance. This will be done by capturing data regarding core stability and athletic performance among athletes. The knowledge gained may assist sport coaches in exercise program prescription and advise sport professionals about different training modalities to enhance sport performance.

It will be expected from all participants to take part in five different functional tests (Appendix B) enclosing measurements of functional performance and core stability grading. Each participant will be asked to fill in a questionnaire beforehand, disclosing socio-demographic information. The tests will take approximately 1hour to complete. Participants that form part of the study must be registered at the University of the Free State, taking part in a first team in one of the qualified sports. Males and females of any age are allowed.

Participation is voluntary. Refusal or withdrawal from the study will involve no penalty or loss of benefit to which participants are otherwise entitled to. Your personal information will remain confidential by the researcher. No financial compensation will be offered to participate in the study. If the results are published, this may lead to cohort identification, but all data will be presented anonymously.

The study is approved by the Health Sciences Research Ethics Committee of the University of the Free State. For any enquiries the secretariat can be contacted at (051) 405 2812.

Please contact Nelmaré with any questions at 073 262 1697 or loubsernp@ufs.ac.za.
Thank you

INLIGTINGSDOKUMENT

KERNSTABILITEIT EN ATLETIESE PRESTASIE VRAELYS EN AFMETINGS

Ek, Nelmaré Loubser, 'n student aan die Universiteit van die Vrystaat is tans besig om my meesters graad in Biokinetika te voltooi. My studie handel oor kernstabiliteit en atletiese prestasie en hoe die twee met mekaar korreleer.

Met hierdie dokument vra ek u om aan my studie deel te neem. Die doel van die studie is om vas te stel of 'n hoër vlak van kernstabiliteit verwant is aan verbeterde atletiese prestasie. Die bogenoemde sal bepaal word deur data te versamel wat kernstabiliteit en atletiese prestasie meet. Die resultate en kennis wat verkry word, kan afrigters, persoonlike afrigters en professionele atlete help in verband met program voorskrif asook watter oefen modaliteite gebruik kan word om atletiese prestasie te bevorder.

Daar sal van alle deelnemers verwag word om vyf funksionele toetse wat kernstabiliteit en atletiese prestasie meet, af te lê (Appendix B). Elke deelnemer sal gevra word om 'n vraelys in te vul met al alle nodig inligting voordat die toetse afgelê word.

Die toetse sal in geheel een uur duur. Alle deelnemers moet geregistreer wees by die Universiteit van die Vrystaat en deel wees van 'n eerste sportspan. Mans en vrouens van enige ouderdom sal toegelaat word om deel te neem.

Deelname is vrywillig. Deelnemers mag ten alle tye van die studie ontrek sonder dat enige boete toegestaan sal word. Alle persoonlike inligting sal konfidensieel hanteer word deur die navorser en geen finansiële vergoeding sal aan deelnemers toegestaan word nie.

Indien die resultate publiseer word sal alle data anoniem voorgestel word.

Die studie is goedgekeur en aanvaar deur die Gesondheidswetenskap se Etiese Navorsingskomitee aan die Universiteit van die Vrystaat. Vir enige verdere vrae kan die Sekretaresse geskakel word by (051) 405 2812.

Indien enige vrae skakel Nelmaré by 073 262 1697 of loubsernp@ufs.ac.za.
Dankie

INFORMED CONSENT

2017

ATHLETIC PERFORMANCE SURVEY/MEASUREMENTS AMONG ATHLETES

You are hereby asked to participate in a research study conducted by Nelmaré Loubser, from the Exercise and Sports Science Department at the University of the Free State. The results of this research will form part of the dissertation for her Master's degree. You have been identified as a possible participant in this study because you are taking part in university sport and this dissertation is based on athletic performance among varsity athletes.

The aim of this study is to determine the correlation between core stability and athletic performance.

This will be done by collecting data that involves measurements of core strength and athletic performance during different functional movements. Before testing starts, information sessions will be held at each testing station to explain the procedure and the correct technique for every movement.

Each of the participants will receive a scoring sheet where the researcher will capture the results of all the different tests. This detail will be apparent on the data sheet.

The data will be captured over a period of one hour. The following variables will be measured during the test: the level of core strength by doing a double leg lowering test (DDL); lower body power, measured by the height of a vertical jump; upper body power, measured by the distance of a medicine ball chest throw; lower body speed and power, measured by the time in seconds during the forty-meter sprint and agility and power, measured by the time in seconds to complete a T-test.

The above mentioned tests occur under maximal effort and therefore increase the risk of injury or physical discomfort.

This research project will provide valuable information to participants and coaches regarding functional performance and how core stability/strength contributes to the level of performance. The results will also provide conditioning coaches and athletes with valuable information that can assist with the development of individualised and specific exercise programme prescription and rehabilitation techniques to improve sport performance.

Unfortunately there will be no payment for your participation in this study, but a comprehensive report of the outcomes will be issued on request.

Any information that is obtained regarding this study will remain confidential and will be disclosed only with your permission or as required by law. Anonymity will be maintained by means of allocating numbers to participants. Information will be kept by the researcher only and raw data held in files stored in a locked office. All processing of data will be protected by a Computer password protector. Only the findings will be published with the strictest of confidentiality to the individual athletes.

Participation in this study is voluntary. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study if information needed is not compulsory and will not affect the results.

If you have any questions or concerns about the research, please feel free to contact Nelmaré Loubser (+27 732621697; Email: loubsernp@ufs.ac.za or Professor Derik Coetzee (051 401 2944- Department Exercise and Sports Sciences, University of the Free State).

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, you may contact the secretariat of the HSREC, UFS on (051) 405 2812.

The information above was described to me, __________________________, by Nelmaré in *English/Afrikaans* and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent to voluntarily participate in this study.

__________________ ___________

Name of participant Date

____

Signature

I declare that I explained the information given in this document to ___________________, and their participation _____________________ was encouraged and ample time was given to ask me any questions. This conversation was conducted in English/Afrikaans and *no translator was used.*

____________________ ____________

Name of Researcher Date

________________________ ______________

Signature Date

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INGELIGTE TOESTEMMING

2017

ATLETIESE PRESTASIE VRAELYS EN AFMETINGS VAN ATLETE

Hiermee word u gevra om deel te neem aan 'n studie wat deur Nelmaré Loubser, 'n student aan die Universiteit van die Vrystaat afgelê word. Die resultate van die onderskeie toetse sal dien as deel van haar skripsie vir haar meestersgraad. U word as deelnemer klassifiseer omdat u registreer is as Kovsie student en deelneem aan 'n eerste sportspan.

Die doel van die studie is om die verwantskap tussen kernstabiliteit en atletiese prestasie te bepaal.

Hierdie verwantskap sal bepaal word deur data wat kernstabiliteit en atletiese prestasie tydens funksionele bewegings meet te versamel. Daar sal 'n inligtingsessie voor elke toetsstasie wees om die volledige beweging en korrekte tegniek aan u te verduidelik.

Elke deelnemer sal 'n papiertjie ontvang waarop sy uitslae vir elke toets noteer gaan word. Hierdie data sal na afloop van die toets op 'n data lys ingevoer word.

Data sal oor 'n periode van 60 minute versamel word. Die volgende veranderlikes gaan gemeet word tydens die toetsings: vlak van kernstabiliteit deur middel van 'n dubbel been sak toets; onderlyf eksplosiewe krag deur middel van 'n vertikale sprong; bo lyf eksplosiewe krag deur middel van 'n borsgooi met 'n medisynebal; onderlyf spoed en krag deur middel van die tyd wat dit neem om 'n veertig meter sprint te voltooi; spoed en ratsheid deur middel van die tyd wat dit neem om 'n T-toets te voltooi.

Die bogenoemde toetse vind plaas in maksimale uitset en verhoog dus die risiko op besering en fisiese uitputting.

Die navorsingsprojek sal nuttige inligting aan deelnemers en afrigters verskaf in verband met funksionele prestasie en hoe kernstabiliteit bydra tot die vlak van prestasie. Die resultate sal ook kondisioneringsafrigters en atlete met waardevolle inligting voorsien wat hulle kan assisteer in die ontwikkeling van geïndividualiseerde en spesifieke oefen program voorskrif en rehabilitasie tegnieke om sportprestasie te verbeter.

Ongelukkig sal daar geen vergoeding wees vir enige deelnemer wat aan die studie deelneem nie, maar 'n verslag van elke individu sal verskaf word aan die deelnemer indien hy daarvoor vra.

Alle inligting wat deur hierdie studie verkry word sal konfidensieel hanteer word en slegs gebruik word soos deur die wet voorgeskryf. Deelnemers sal nommers ontvang wat hulle identifiseer om sodoende anoniemiteit te behou. Alle data sal op 'n rekenaar met 'n wagwoord gestoor word. Alle bevindinge wat publiseer word sal hoogs konfidensieel gedoen word.

Deelname aan hierdie studie is vrywillig. Indien u instem om aan hierdie studie deelneem het u die reg om enige tyd te ontrek sonder enige nagevolge. U mag ook weier om vrae wat u ongemaklik laat voel te antwoord en steeds deel te neem indien die inligting nie van belang is vir die studie om voltooi te word nie

Indien u enige vrae het oor die navorsing skakel graag vir Nelmaré Loubser by (+27 732621697; Epos: loubsernp@ufs.ac.za of vir Prof. Derik Coetzee (051 401 2944- Departement Oefen en Sportwetenskappe, Universiteit van die Vrystaat).

U mag ten alle tye u toestemming terugtrek en ontrek van die studie sonder enige boete. Indien u vrae het oor u regte as deelnemer in hierdie studie, kan u die Sekretaresse van die Gesondheidswetenskappe se Navorsing Etiese komitee van die UFS skakel by (051) 405 2812.

Die bogenoemde inligting was aan my_________________________ verduidelik deur Nelmaré Loubser in Engels en ek is vertroud met hierdie taal. Ek is die geleentheid gegee om vrae te vra en is ook beantwoord indien nodig was.

Hiermee gee ek toestemming om vrywilliglik deel te neem aan die studie

______________________________ --------------------------

Naam van deelnemer Datum

____

Handtekening

EK verklaar dat ek die inligting van hierdie dokument verduidelik het aan _________________________en dat hulle deelname aangemoedig was maar dat daar ook genoeg tyd toegestaan was aan ______________________ om vrae te vra en ook te beantwoord indien nodig. Die gesprek was onderneem in Engels.

_____________________ ____________

Naam van Navorser Datum

________________________ ______________

Handtekening Datum

APPENDIX G:
PERMISSION LETTERS

PERMISSION LETTER

To: Tirsa Pittaway
Department of Exercise and Sport Sciences
Faculty of Health Sciences
UFS

RE: RESEARCH PROJECT ON ATHLETIC PERFORMANCE AND CORE STABILITY

With this letter I would like to request your permission to use your centre as a site for a research study conducted by the University of the Free State, Exercise and Sport Science Department. I am requesting access to all registered gym members as well as free entrance to all participants not registered as a member in your gym.

The research forms part of a master's degree in Biokinetics at the University of the Free State. The aim is to determine the level of core stability and then compare it with the athletic performance and determine if these two variables have a correlation. This will be done by collecting measurements regarding the level of core strength by doing a double leg lowering test (DDL); lower body power, measured by the height of a vertical jump; upper body power, measured by the distance of an overhead medicine ball throw; lower body speed and power, measured by the time in seconds during the forty-meter sprint and agility and power, measured by the time in seconds to complete a T-test. The knowledge gained may assist sport coaches in program prescription and also provide sport professionals with different training modalities to enhance sport performance.

All sports teams of the University of the Free State will be visited where information regarding the testing, will be explained. It will also provide an opportunity for athletes to volunteer as participants in the study. Measurements of functional movements will be used to test athletic performance and data will be collected on a scoring sheet. As soon as the informed consent has been signed, the athlete will be tested after explaining all the techniques and procedures. The information gathered from the tests will be analysed and the results will be used to develop sport enhancement programmes for future athletes.

This study is beneficial for current participants, athletes, coaches and sport professionals. This study will also assist coaches, athletes and rehabilitation professionals with exercise program prescription that enhances athletic performance.Participants will not be placed at risk and the information gathered will be handled with confidentiality by the researcher. All participants will complete an informed consent form. Participation is voluntary. Athletes may decide not partake in the study.

If you have any questions or concerns regarding how the tests are conducted conduction of the tests you may contact the secretariat of the HSREC, UFS on (051) 405 2812.

Your assistance in this matter will be greatly appreciated.

Please contact me with any questions: 051 401 9540 or loubsernp@ufs.ac.za
Kind regards

I hereby give permission that the centre may be used as testing facility for this project.

2017/01/17

Signature ____________________ Date ____________

PERMISSION LETTER

To: DB Prinsloo
Kovsie Sport
UFS

RE: RESEARCH PROJECT ON ATHLETIC PERFORMANCE AND CORE STABILITY

With this letter, I would like to request your permission to test all the athletes of the University participating in the various sport codes as part of a research study. The tests will make use of the athletes on the High performance package and it will be a service granted to all the athletes to monitor their performance ensuring they are highly conditioned and well trained. The tests will be conducted by the University of the Free State, Exercise and Sport Science Department. The researcher has requested from Mrs T. Pittaway access to all registered gym members as well as free entrance to all participants not registered as a members in the gym.

The research forms part of a master's degree in Biokinetics at the University of the Free State. The aim is to determine the level of core stability and then compare it with the athletic performance and determine if these two variables have a correlation. This will be done by collecting measurements regarding the level of core strength by doing a double leg lowering test (DDL); lower body power, measured by the height of a vertical jump; upper body power, measured by the distance of an overhead medicine ball throw, lower body speed and power, measured by the time in seconds during the forty-meter sprint and agility and power, measured by the time in seconds to complete a T-test. The knowledge gained may assist sport coaches in program prescription and also provide sport professionals with different training modalities to enhance sport performance.

All sports teams of the University of the Free State will be visited where information regarding the testing will be explained. It will also provide an opportunity for athletes to volunteer as participants in the study. Measurements of functional movements will be used to test athletic performance and data will be collected on a scoring sheet. As soon as the informed consent has been signed, the athlete will be tested after explaining all the techniques and procedures. The information gathered from the tests will be analysed and the results will be used to develop sport enhancement programmes for future athletes. This study is beneficial for current participants, athletes, coaches and sport professionals. This study will also assist coaches, athletes and rehabilitation professionals with exercise program prescription that enhances athletic performance.

Participants will not be placed at risk and the information gathered will be handled with confidentiality by the researcher. All participants will complete an informed consent form. Participation is voluntary. Athletes may decide not to partake in the study. If you have any questions or concerns regarding how the tests are conducted you may contact the secretariat of the HSREC, UFS on (051) 405 2812.

Your assistance in this matter will be greatly appreciated.

Please contact me with any questions: 051 401 9540 or loubsernp@ufs.ac.za

Kind regards

I hereby give permission that all athletes may be tested with their consent.

__________________ ____________

Signature Date

PERMISSION LETTER

August 2016

To: Health Sciences Research Ethics Committee

RE: APPROVAL FROM UFS AUTHORITIES FOR A RESEARCH PROJECT ON ATHLETIC PERFORMANCE AND CORE STABILITY

With this letter I would like to request your permission from you to test students registered at the University of the Free State. The students used will be form part of the athletes of the University of the Free Sate participating in the various sport codes as part of a research study.

According to the Kovsie Sport data basis, there are approximately 160 males and 100 female athletes registered at the University of the Free State representing the first teams in the different sport codes. The Kovsie Fit gym on campus is an exercise centre facilitating all varsity athletes to accomplish their dreams and accommodate athletes of all different kinds of sports. From the sport department, a certain amount of athletes are granted a High Performance package that includes training, testing and personal assistance at a very low cost. The aim of the facility is to enhance the University's Athletes in every possible aspect of their sport. To be able to do that, the athletes should be tested on a regular basis to track their performance and to work on the areas in which they do not perform optimal yet. All the athletes are invited to participate in the study and can be part of this research project. The researcher will go to training sessions to invite and inform all athletes about the study and the tests that will take place. All the athletes of the University of the Free State's Sport teams will be granted the opportunity to be tested.

An informed consent form (Appendix D) approved by the University of the Free State's HSREC and Department of Exercise and Sport Science will be handed out to be signed by each participant to continue with the testing.

The testing of students will make out part of the High performance package and will be a service granted to all the athletes to monitor their performance thus ensuring they are highly conditioned and well trained. The tests will be conducted by the University of the Free State, Exercise and Sport Science Department. The researcher did request access to all registered gym members as well as free entrance to all participants not registered as a member in the gym.

The research forms part of a master's degree in Biokinetics at the University of the Free State.

The aim is to determine the level of core stability and then compare it with the athletic performance and determine if these two variables have a correlation. This will be done by collecting measurements regarding the level of core strength by doing a double leg lowering test (DDL); lower body power, measured by the height of a vertical jump; upper body power, measured by the distance of an overhead medicine ball throw; lower body speed and power, measured by the time in seconds during the forty-meter sprint and agility and power, measured by the time in seconds to complete a T-test. The knowledge gained may assist sport coaches in exercise program prescription and also provide sport professionals with different training modalities to enhance sport performance.

All Kovsie sport teams will be visited where information regarding the testing will be explained. It will also provide an opportunity for athletes to volunteer as participants in the study. Measurements of functional movements will be used to test athletic performance and data will be collected on a scoring sheet. As soon as the informed consent has been signed, the athlete will be tested after explaining all the techniques and procedures. The information gathered from the tests will be analysed and the results will be used to develop sport enhancement programmes for future athletes. This study is beneficial for current participants, athletes, coaches and sport professionals. This study will also assist coaches, athletes and rehabilitation professionals with exercise rogram prescription that enhances athletic performance.

Participants will not be placed at risk and the information gathered will be handled with confidentiality by the researcher. All participants will complete an informed consent form. Participation is voluntary. If you have any questions or concerns regarding how the tests are conducted you may contact the secretariat of the HSREC, UFS on (051) 405 2812.

Your assistance in this matter will be greatly appreciated.

Please contact me with any questions: 051 401 9540 or loubsernp@ufs.ac.za

Kind regards

I hereby give permission that all athletes may be tested with their consent.

HSREC 17

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS·UV HEALTH SCIENCES GESONDHEIDSWETENSKAPPE

UFS UV
2016 -10- 06
Faculty of Health Sciences

HEALTH SCIENCES RESEARCH ETHICS COMMITTEE

APPROVAL FROM UFS AUTHORITIES
FOR PARTICIPATION OF STUDENTS/STAFF IN RESEARCH PROJECTS

Title, Initials, Surname:	Miss N.P. Loubser	**Staff/Student number**	0874191
Department/Institution:	Exercise and Sport Sciences		
Phone:	051 401 9540	**E-mail address:**	nelmareloubser@hotmail.com
Supervisor(s):	F. Coetzee, C. Francisco	**Phone:**	2944; 2323

Protocol Title:	The correlation between core stability and athletic performance amongst athletes.

Who will be involved in the study? (tick ✓)	☐ UFS Personnel	☑ Students

SECRETARY
OFFICE OF THE DEAN
STUDENT AFFAIRS
18 -10- 2016
UNIVERSITY OF THE FREE STATE

INSTRUCTIONS:

I. Please attach the following to this form when requesting approval from the signatories:
   a. The study protocol; and
   b. The Health Sciences Research Ethics Committee (HSREC) application form.

II. Kindly note that it is the responsibility of the researcher(s) to ensure that all relevant signatures are obtained before this signed form is returned to HSREC Administration (D104) Francois Retief Building, Faculty of Health Sciences, UFS. The protocol may, however, be submitted for HSREC approval while signatures are being obtained.

III. Please choose either section A **OR** B below.

IV. Section C is **mandatory** for all research on campus.

HSREC 17

A. FOR RESEARCH ON UFS STUDENTS AND/OR STAFF FROM A SPECIFIC FACULTY, **BOTH** THE FOLLOWING SIGNATURES MUST BE OBTAINED:		
I. HEAD OF SCHOOL (IF APPLICABLE):	☒ Approved	☐ Not Approved
Signature:	**Date:**	
	04/10/2016	
Comments:		

II. DEAN OF FACULTY:	☒ Approved	☐ Not Approved
Signature:	**Date:**	
	Dean: Faculty of Health Sciences University of the Free State 12 -10- 2016 Dekaan: Fakulteit Gesondheidswetenskappe Universiteit van die Vrystaat	
Comments:		

OR

B. FOR RESEARCH ON INTERFACULTY UFS STUDENTS AND/OR STAFF AND/OR STUDENTS IN UFS RESIDENCES, THE FOLLOWING SIGNATURE MUST BE OBTAINED:		
I. DEAN: STUDENT AFFAIRS	☐ Approved	☐ Not Approved
Signature:	**Date:**	
	01 — 11 — 2016	
Comments:		

AND

C. ALL RESEARCH ON STUDENTS AND/OR STAFF TO BE APPROVED BY:		
I. VICE-RECTOR: RESEARCH	☒ Approved	☐ Not Approved
Signature:	**Date:**	
	07/11/2016.	
Comments: Prof. Corli Witthuhn Viserektor:Navorsing - Vice Rector:Research Universiteit van die Vrystaat University of the Free State Hoofgebou K61 Tel. 051 - 401 2116	Die Universiteit van die Vrystaat The University of the Free State 2016 -11- 07 Prof. R.C. Witthuhn VISEREKTOR: NAVORSING VICE RECTOR: RESEARCH	

Confidentiality Statement

2017

CORE STABILITY AND ATHLETIC PERFORMANCE AMONG VARSITY ATHLETES

Hereby I, ________________________________ agree that all information I gather during testing are highly confidential. I promise to not discuss or record any of the data for my own purpose or gain.

____

Name and Surname of personnel: **Date:**

____

Signature:

____

Name of witness: **Date:**

____

Signature:

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CORE STABILITY AND ATHLETIC PERFORMANCE AMONGST UNIVERSITY ATHLETES

NELMARé LOUBSER

APPENDIX M: LETTER FROM LANGUAGE EDITOR

20 January 2018

Luna Bergh

55 Jim Fouché Avenue

Universitas, Bloemfontein

To whom it may concern

This is to certify that I language-edited Nelmaré Loubser's dissertation manually, excluding references and appendices. The author's style was retained and she effected the changes herself. In this way both linguistic excellence and the candidate's ownership of her text were ensured.

Sincerely

Luna Bergh

D Litt et Phil

Language and writing specialist