Lumbo-pelvic core stability: Profiles of female long-distance runners

A mini-dissertation by

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DECLARATION

I, Lindie Pool, certify that the report hereby submitted for the degree M.Sc.Physiotherapy (Clinical Sport Physiotherapy) at the University of the Free State is my independent effort and had not previously been submitted for a degree at another university/faculty. I furthermore waive copyright of the report in favour of the University of the Free State.

04 October 2016

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TO GOD BE THE GLORY

SUMMARY

Running is a sport characterised by a 90% prevalence of predominantly lower-limb overuse injuries. Stress urinary incontinence (SUI) is also prevalent and its hindrance in terms of participation falls within the definition of running injuries. Neuromuscular mechanisms within the proximal kinetic chain have been correlated to these injuries and conditions, however contrasting views exist. Adaptations within the tonic and phasic characteristics of core musculature have been shown to elicit a series of kinetic adaptations within the movement system predisposing injury/recurrence of injury.

The aim of this research was to discuss the changes in core muscle characteristics in relation to risk of injury after exposure to a functional activity. Changes were presented by means of profiling. A secondary objective was to identify numerous internal and external risk factors of running-injury.

A descriptive, cohort analytical study design was used with a convenience sample of fifteen (15) eligible experienced female long-distance runners registered in Bloemfontein-based accredited running-clubs. The baseline- and post-exercise profiling test battery included electromyography (EMG) of the pelvic floor muscles (PFM) and M. Transversus Abdominus (TrA)(ICC 0.98), pressure biofeedback testing (PBU) (ICC 0.90) and functional endurance testing (ICC 0.97). Any 24+ km functional longrun served as functional task. External, internal and demographic factors were identified using a self-compiled questionnaire.

The majority of the TrA EMG, PBU and Dominant-Side lateral muscle group profiles displayed an increase in post-exercise value. The profiles illustrated both failure (decrease in value) and or possible neuromuscular mechanisms (increase in value) attempting to augment stability. These mechanisms are suggestive of a loss of stability on a more central level. The cohort also displayed remarkably low-level integrated stability activity (PBU) both at baseline and post-exercise. There were no statistical significant difference between the baseline and post-exercise profiles for any of the PFM ($p=0.7957$), TrA ($p=0.2769$), PBU ($p=0.1875$), Anterior Muscle Group ($p=0.1688$), Posterior Muscle Group ($p=0.1909$), Lateral Dominant Muscle Group ($p=0.5897$) or Non-Dominant Lateral Muscle Group measurements ($p=0.1848$).

Knee injury was identified as the most prevalent previous running injury (47%). Only 20% of the 67% of participants that included muscle conditioning in training programs included the PFM. Running training errors were the most significant external causative factors present within the cohort together with insufficient periodisation and recovery from longruns.

The results of this research support the inclusion of core-stability components in running injury risk management and rehabilitation. The major limitations of this research were the small sample size and absence of a control group. This may be addressed by future research on valid functional core testing. Future research should also establish scientific indicators of fatigue and correlation between core-characteristics and risk of injury.

ACRONYMS AND ABBREVIATIONS

Kilometer	*km.*
M. Transversus Abdominus	*TrA*
Pelvic floor muscles	*PFM*
Ground reaction force	*GRF*
Long slow distance run	*LSD*
Body mass index	*BMI*
Centimetres	*cm*
Kilograms	*kg*

NOMENCLATURE

Core/Lumbo-pelvic core

Active lumbo-pelvic core stability refers to the integrated ability of the local and global musculature of the lumbo-pelvic-hip complex to control the position of the trunk, pelvis and lower limb to ensure optimal positional force and motion transfer within the integration of kinetic chain activities during running (Comerford & Mottram, 2001). For the purpose of this study, the 'core' will only refer to the local and global stability muscles.

Long-distance runner

A 'typical' distance-runner can be regarded as a person predominantly covering a 20-30 km weekly distance for at least one to three years (Hreljac, 2005:651). Therefore, for the purpose of this study a 'typical' long-distance runner may be regarded in theory as a female running more than a weekly 30km for the same amount of years. For the purpose of this research, a long-distance runner refers to a female runner who has completed a road-marathon and that competes and predominantly trains on tarmac road.

Running injury

There is no clear definition on the classification of a running injury. However, several authors agree upon limitation in regularity of running sessions and a decrease in mileage and running speed over a period of seven days to constitute a running injury (Hreljac, 2005:651).

Overuse injury

An overuse injury can be defined as a musculoskeletal complaint caused by abnormal loads on associated musculoskeletal structures over a period of time. Overuse injuries result from repetitive musculoskeletal loading without sufficient rest (DiFiori, *et al.*, 2014:3; Hreljac, 2005:652; Bruckner & Khan, 2012:25).

LSD/longrun

For the purpose of this study a LSD refers to any distance of twenty-four or more (24 +) kilometers similar to the distance used in training programs for runners. This LSD longrun will be introduced as a functional task in compilation of the baseline- and post-exercise profiles of the subjects.

Muscle Endurance

Muscular endurance is a muscle's ability to complete a movement repetitively in a certain period of time. It also represents the muscle's ability to resist fatigue (Kaukab & Abdulhameed, 2013:155).

Running Season/ In-season

For the purpose of this research, the running season or in-season refers to the six weeks of training before a marathon or longrun of at least24 km.

Off-season

For the purpose of this research, the off-season refers to the six weeks after completion of each participant's final competitive race/longrun of more than 24 km. This concept will be used only to investigate periodisation within the sample.

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND AND MOTIVATION

Running as recreational and competitive sport is ever growing in popularity. The appeal in running lies in the installed sense of achievement and mental determination accompanied by numerous positive physical and social aspects. In spite of these benefits, injury is mentioned as the major detrimental component of running (Major, 2001: 16-20).

Runners suffer from a significant amount of injuries with a reported 90 % yearly incidence for marathon runners (Fredericson & Misra, 2007:437). Two point five to five point eight (2.5-5.8) overuse injuries occur per one thousand hours of both distance-and long-distance running (Nielsen, Buist, Sorensen, Lind & Rasmussen, 2012:58). Furthermore, 6.2% - 17.9% of marathon runners make use of medical posts during races (Van Gent, Siem, Van Middelkoop, Van Os, Bierma-Zeinstra & Koes, 2007:470).

Overuse running-injuries are more prevalent than acute injuries (Hreljac, 2005:651). Predominantly, 94.3% of injuries are of the lower limb. (Taunton, Ryan, Clement, Lloyd-Smith & Zumbo, 2002:96 ; Lopes, Hespanhol, Yeung, Oliveira & Leonardo, 2012:897). Achilles tendinopathy, medial tibial stress syndrome and plantar fasciitis are reported for distance runners, while long-distance runners suffer from patellofemoral-pain along with achilles tendinopathy (Taunton *et al*., 2003:96). Low back pain is also a complaint in 3.4%-10% of all runners (Hamill, Moses & Seay, 2009:261).

Gender differences exist in overuse injuries, with female runners representing a significantly higher percentage of complaints (Taunton *et al*., 2003:96). Significant to the present research report are the angular differences in the female pelvis in comparison to its male counterpart (Schache, Blanch, Rath, Wringley & Bennell, 2003:114-116).

Contrary to popular belief, Schache *et al.* (2003:113) considers the female pelvis not to be anatomically wider. The anatomical changes within the female pelvis secondary to pregnancy and parity is however extensively supported by literature. The influence of these adaptations on the lumbo-pelvic-hip complex/core is discussed in this report as the core provides the base of stability for the kinetic chains (Bruckner & Khan, 2012:38).

The kinetic chain of any athlete refers to the integrated and coordinated movement of the joints and limbs (Bruckner & Khan, 2012:38). The individual segments within the chain must move in a pre-programmed, specific order to effectively perform a task (Kibler, Press & Sciascia, 2006:192).

The lumbo-pelvic core provides the proximal musculoskeletal base of stability for the activation of successive links within the lower limb kinetic chain with the basic sequence being from proximal to distal. This lumbo-pelvic stability system/core (2.1) is an integration of the passive, neural and active subsystems (Panjabi, 1992, Hoffman & Gabel, 2013). The active subsystem consists of the local and global lumbopelvic stability muscles and the global mobility muscles (Comerford & Mottram, 2001:22 ; Bruckner & Khan, 2012: 211). The latter serves as focus of this research as valid and reliable testing procedures have been described for muscle characteristics (2.5).

The core further allows adequate distribution of forces from the lower limbs to the spine and upper limb (Bruckner & Khan, 2012:38 & 66). Adaptation or injury to any link within the chain may cause local dysfunction, but may also involve the distal and proximal areas. Any suboptimal chain of events can be regarded as a significant overuse mechanism for running injuries (Comerford & Mottram, 2001:4).

On the one hand, ideal distal running mechanics is necessary to optimize the size and direction in which the already increased ground reaction force (GRF) is distributed from the foot to the more proximal areas. Female runners display increased amplitudes of pelvic and hip movement along with increased stride length during running (Schache *et al.,* 2003:114-116). For these exact reasons, numerous studies on biomechanics and injury focus on the female running population (Gerlach, White, Burton, Dorn, Leddy & Horvath, 2004:658).

Any adaptations that take place may result in the abnormal loading of multiple foot, knee, hip and even lumbo-pelvic structures predisposing numerous overuse injuries (Bruckner & Khan, 2012:66-67). As a result, a tendency developed to investigate etiology of running injuries in terms of lower-limb mechanics distal to the area of pain and local muscle characteristics (Duffey, Martin, Cannon, Craven & Messier, 2000:1826 ; Paluska, 2005:1007).

On the other hand, the dynamic running body relies on effective and adequately timed co-ordination of the proximal lumbo-pelvic-hip/core muscles for balance and support within the kinetic chain to enhance joint placement for effective attenuation of the GRF. The integration of the local and global stability musculature of the lumbo-pelvic core is crucial as neither system can control functional stability in isolation and both systems contribute to force production. Consequently the combination of slow and fast motor units in this integrated system subjects the system to fatigability (Comerford & Mottram, 2001:16).

Muscle fatigue has been shown to induce alteration in proprioceptive repositioning of the lumbar spine, knee and ankle due to aberrant afferent information resulting in a decrease in excitability of γ-motor neurons (Boucher, Abboud & Descarreaux, 2012:662). As a result the dominance of tonic motor neurons are decreased during sustained low-load contractions by changing the order of recruitment of motor neurons in the fatigued musculature. The low-load, repetitive and prolonged nature of running may therefore result in a decrease in segmental control along with sub-optimal local and distal joint placement predisposing both injury and pain (Comerford & Mottram, 2001:16).

Thus, the assessment of the proximal areas in injury etiology is warranted with the lumbo-pelvic core's ability to resist fatigue as priority. Despite the theoretic rational, evidence to date to support assessment and training of local stability muscles are poor, especially with no history of local pain or injury (Mottram & Comerford, 2008:41). Only the studies by Holmich *et al.* (1999) and Sherry & Best (2005) have reported beneficial application of core stability training on rehabilitation of groin and hamstring sporting injuries respectively. Core stability is however generally included in most rehabilitation and athletic training regimens (Gamble, 2007:58).

No single gold-standard measurement is described or suggested for lumbo-pelvic stability (Bruckner & Khan, 2012:213). This is to be expected as the predominant neuromotor characteristics of the local musculature differ from the more phasic global muscles. Techniques commonly used by investigators in core-stability studies include electromyography (EMG), isometric endurance testing and ultrasound imaging (Bruckner & Khan, 2012:214).

The use of singular and isolated muscle testing procedures is questionable as integrated control of multiple muscular groups are necessary to ensure an optimal functional task (Kibler, Press & Sciascia, 2006:191). A battery of tests may therefore be applicable to serve as gold-standard tool for the lumbo-pelvic core. No studies reviewed for this research identified or suggested a battery of tests to investigate integrated core characteristics. Research on core-stability do however include multiple testing positions, but without the ability to distinguish between muscle characteristics (McGill, Childs & Lieberman, 1999; Kibler *et al.*,2006). No studies reviewed for this research identified or suggested a battery of tests to investigate integrated core characteristics.

Core endurance, rather than strength, may also be more applicable to a population of long-distance runners. A test battery should therefore include valid and reliable functional endurance tests, tests that display both local and global core muscle-characteristics and finally have the ability to detect change. This research attempt therefore utilized a battery of tests illustrated in literature to be both valid and reliable aswell as suitable for test-retest purposes as is necessary in profiling (2.5.).

Profiling is common clinical practice in athletes to asses risk of injury and to enhance performance. Mottram & Comerford (2008) pioneered the idea of multi-factorial profiling of functional movement including the lumbo-pelvic core. These authors suggest that identifying, addressing and re-assessing weak links within core-stability may reduce risk of injury (Mottram & Comerford, 2008:40). No other research was found in terms of core-stability and multi-factorial profiling.

Screening, rather than profiling, is used to determine risk of injury in research injury in sport. However, no screening test with adequate statistical test properties exists in terms of injury prevention including core-stability (Bahr, 2016). Therefore, in the absence of screening and gold- standard testing, profiles drawn from a battery of valid and reliable tests for the lumbo-pelvic core may prove suitable to display how the local and global core-muscles of female runners respond to a functional low-load endurance task such as the long, slow distance run.

The purpose of this research was to identify and discuss changes in the local and global lumbo-pelvic muscle-characteristics of female long-distance runners after a long slow distance run by means of profiling. These changes provide further insight to the plausibility of core training to reduce risk of injury within a population with a significant prevalence of lower-limb overuse injury. This report also highlights numerous internal and external factors prevalent within the study sample. These factors have been proven to influence optimal core functioning and to increase risk of overuse injury. The factors should therefore be considered in the interpretation of muscle characteristics and addressed in injury prevention strategies for female runners.

1.2. AIMS AND OBJECTIVES

1.2.1. AIMS

The main aim of this research was to compile individual profiles of the muscle characteristics of the active subsystem of the lumbo-pelvic core in female long-distance runners.

1.2.2. OBJECTIVES

The primary objective was to compile individual profiles of the muscle characteristics of the active subsystem of the lumbo-pelvic core in female long-distance runners both at baseline and after a functional activity. The changes in the profiles were then discussed in relation to movement dysfunction and therefore risk of overuse injury. A battery of tests proposed in literature was used to identify changes within the individual profiles to be discussed in relation to risk of overuse injury.

A secondary objective was therefore to identify and describe internal and external risk factors of overuse injury prevalent within the cohort of female long-distance runners. These factors include both risk factors of injury and factors that influence optimal core-muscle functioning.

1.3. OUTLINE OF THE SCRIPT

An in-depth discussion on the lumbo-pelvic core and its proposed relation to overuse injury follows in Chapter 2. Chapter 3 outlines the methodology and ethical considerations for this research. Finally, Chapter 4 and 5 comprise of the analysis and discussion of data respectively. The report will conclude with a summary of the findings.

CHAPTER 2

LITERATURE REVIEW

A variety of lower-limb and lumbo-pelvic overuse injuries have been identified in female runners (Lopes *et al.,* 2012: 895-902). This overuse stems from a disruption in one or multiple links of the kinetic chain. The lumbo-pelvic core forms a base of stability and load transfer for optimal running mechanics and force-production (Bruckner & Khan, 2012:66). The inability of the core to resist fatigue may result in dysfunction of movement in the entire kinetic chain, predisposing overuse injuries (Comerford & Mottram, 2001:16). This chapter will discuss the characteristics and functional role of the lumbo-pelvic core stabilisers in long-distance running along with other factors predisposing overuse running injuries.

LITERATURE DATABASE

An extensive literature search was conducted between January 2013 and May 2016. The following search engines were utilised: Pubmed, MEDLINE, UFS Journal Search, Science Direct and SportDiscuss. Keywords included: "lumbo-pelvic stability", "core stability", "running and injury", "injury and core stability" and "fatigue and running".

2.1. THE LUMBO-PELVIC CORE

The lumbo-pelvic core musculature plays a vital part in the kinetic chain of the running body as it provides local stability, but also provides a stable base for the distal components to function within optimal position, timing and velocity (Kibler, Press & Sciascia, 2006:190). No one definition has been proposed for lumbo-pelvic core stability. For the purpose of this report, lumbo-pelvic core stability refers to the integrated ability of the local and global musculature of the lumbo-pelvic-hip complex to control the position of the trunk, pelvis and lower limb to ensure optimal positional force and motion transfer within the integration of kinetic chain activities during running.

2.1.1. CORE STABILITY

2.1.1.1. THE STABILITY SYSTEM

The groundbreaking work of Panjabi hypothesized the three subsystems of spinal stability (Figure 1). In order to sustain stability and prevent low back symptoms, Panjabi proposed harmonious functioning of all three integrated systems. Dysfunction in any one of the subsystems may then lead to dysfunction in the stability systems in its entirety (Panjabi, 1992:384).

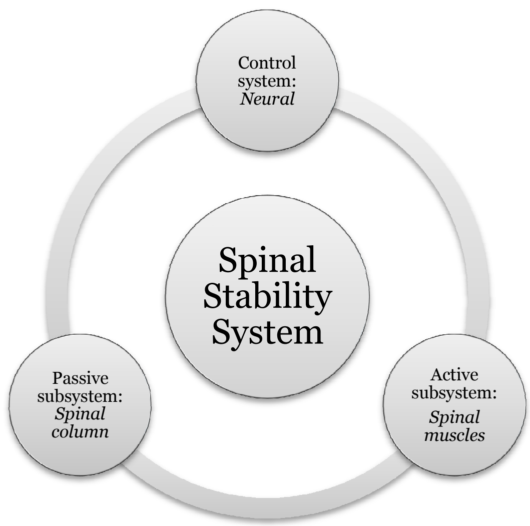


FIGURE 1: THE SPINAL STABILITY SYSTEM

(Panjabi, 1992:384)

Running however involves continuous integration of numerous stability and mobility systems. In terms of the lumbo-pelvic-hip-complex, active stability can be divided into local and global muscle-systems (Table 1) according to muscle fibre dominance, anatomical location, structure, biomechanical potential and consistent and characteristic changes in the presence of dysfunction (Comerford & Mottram, 2001:22 ; Bruckner & Khan, 2012: 211).

TABLE 1: THE CORE STABILITY ACTIVE SUBSYSTEMS

	LOCAL STABILITY	*GLOBAL STABILITY*
Muscles	• M. Transversus Abdominus (TrA) • Pelvic Floor Muscles (PFM) • Segmental M. Multifidus • Posterior M. Psoas • Posterior fibres of M. Oblique Abdominus Internus • Respiratory diaphragm	• M. Oblique Abdominus Externus • M. Oblique Abdominus Internus • Oblique inferior fibres of M. Quadratus lumborum • Anterior M. Psoas • PFM contributions
Characteristics	• Type 1 fibres • Low activation threshold • Predominantly slow motor units • Recruited at < 25% of maximum voluntary contraction (MVC) • Fatigue resistant	• Type 2a"hybrid" or 2b fibres • Low and high activation threshold • Slow and fast motor units • Recruited at 40% + MVC • Fast fatiguing; fast motor units
Functional roles	• ↑ muscle stiffness • ↑proprioception • Minimal length change with contraction • Anticipatory ("feed-forward") of functional load with continuous activity throughout movement • Muscle activity independent of direction	• Generates force to control ROM • Eccentric length change with contraction • Ability to shorten through full inner range, isometric hold of contraction, eccentric control of return: non-continuous and direction dependant

(Comerford & Mottram, 2001:22 ; Bruckner & Khan, 2012: 211)

The global system further consists of global mobility muscles that are categorised as mobilisers or load transfer muscles. The axial-appendicular load transfer muscles of the lower kinetic chain (Table 2) also play a functional role in enhancing stability by stiffening the core via fascial attachments. These muscles are integral to core stability within their capacity to transfer torque and momentum during repetitive, high load integrated kinetic chain activities (Behm, Drinkwater, Willardson & Cowley, 2010:94).

TABLE 2: GLOBAL MOBILITY MUSCLES

Global Mobility Muscles	*Load Transfer Category*
Muscles	Hip flexors • M. Rectus Femoris • M. Sartorius • M. Iliacus • M. Psaos (Major & Minor)
	Hip extensors • M. Gluteus Maximus • M. Semimembranosus • M. Semitendinosus • M. Biceps Femoris (long head)
	Hip adductors • M. Adductor Magnus • M. Adductor Brevis • M. Gracilis • M. Pectineus
(Behm, Drinkwater, Willardson & Cowley, 2010:94)	Hip abductors • M. Tensor Fascia Latae • M. Gluteus Medius • M. Gluteus Minimus

Consequently the classification of muscles may not be as simplistic as muscles may act as a stabiliser and/or a mobiliser in any given “normal” situation. Hoffman & Gabel (2013:4) therefore proposes a biopsychosocial theoretical model to include the mobility subsystems within the stability system of movement (Figure 2).

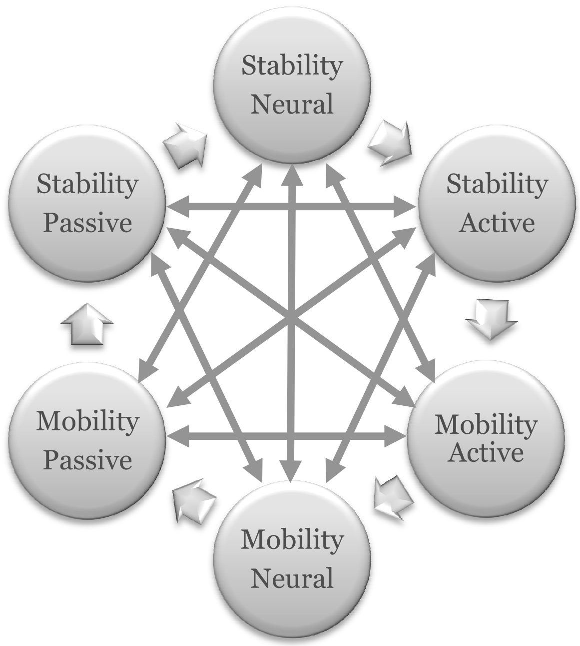


FIGURE 2: THE SIX SUBSYSTEMS OF MOVEMENT

(Hoffman & Gabel, 2013:4)

The functional level of clinical management is determined on the number of subsystems than can be addressed. A synergistic inclusion of all the subsystems in management is expected to achieve the greatest outcome in restoring stability during mobility (Hoffman & Gabel, 2013:5).

2.1.1.2. THE LUMBO-PELVIC CORE AND MOVEMENT DYSFUNCTION

Muscle activation is pre-programmed for running as for any athletic task. This central nervous system activation of the kinetic chain is reinforced by repetition (Kibler, Press & Sciascia, 2006:191). Within the six subsystems of movement (see Figure 2), the neural, or neuromotor, subsystems adjusts the tension in the active subsystems in order to maintain sufficient stability (Hoffman & Gabel, 2013:5).

Movement of the lower limb challenges proximal stability. The central nervous system in response initiates the anticipatory "feed-forward" protective strategy of the local stability muscles. The TrA, lumbar multifidus muscle and PFM are suggested to co-contract or biomechanically “stiffen” in anticipation of lower-limb movement (Hodges & Richardson, 1997:141; Sapsford, 2004:2).

Biomechanical stiffness of the local stability muscles refers to active and/or passive tension resisting a displacing force. This muscular stiffness is reflex-mediated and regulated by muscle spindle afferent input. Adequate positioning of the pelvis and lumbo-sacral spine is dependent on precise muscle spindle input. Inability of the stability muscles to resist fatigue may cause decreased facilitation from the primary spindles. The resulting decrease in proprioception along with the repetitive low load leads to a decrease in dominance of the tonic motor neurons (Comerford & Mottram, 2001:16-17).

Muscle fatigue also increases the sense/perception of effort to activate the slow motor units due to reflex inhibition of the motor neuron pool. This increases a sense of effort occurring on a central nervous system level. Both the local and global systems then display with altered low thresholds (Comerford & Mottram, 2001:16-17). Global muscle efficiency also decreases with fatigue due to length associated changes and changes in directional flexibility and stiffness (Comerford & Mottram, 2001:19).

Therefore the ability of the integrated local and global active systems to withstand fatigue is crucial. Muscle endurance, rather than strength, is needed to ensure sufficient load transfer between the spine and the extremities. The high-threshold global mobilisers are in turn also reliant on this stability to produce torque. As such, dysfunction in the stability systems may lead to a decrease in running performance as the mobilising muscles become more responsive to low threshold stimulus.

Of even greater consequence, it can increase the risk of developing overuse injuries as dysfunction leads to supra-physiological loads secondary to suboptimal lower-limb mechanics. This risk is intensified by the loss of anticipatory recruitment of the local active subsystem that may be persistent in the presence of pain and/or pathology (Comerford & Mottram, 2001:22).

The adapted model of movement dysfunction (Figure 3) displays this intricate role of stability dysfunction in injury causation (Comerford & Mottram, 2001:23).

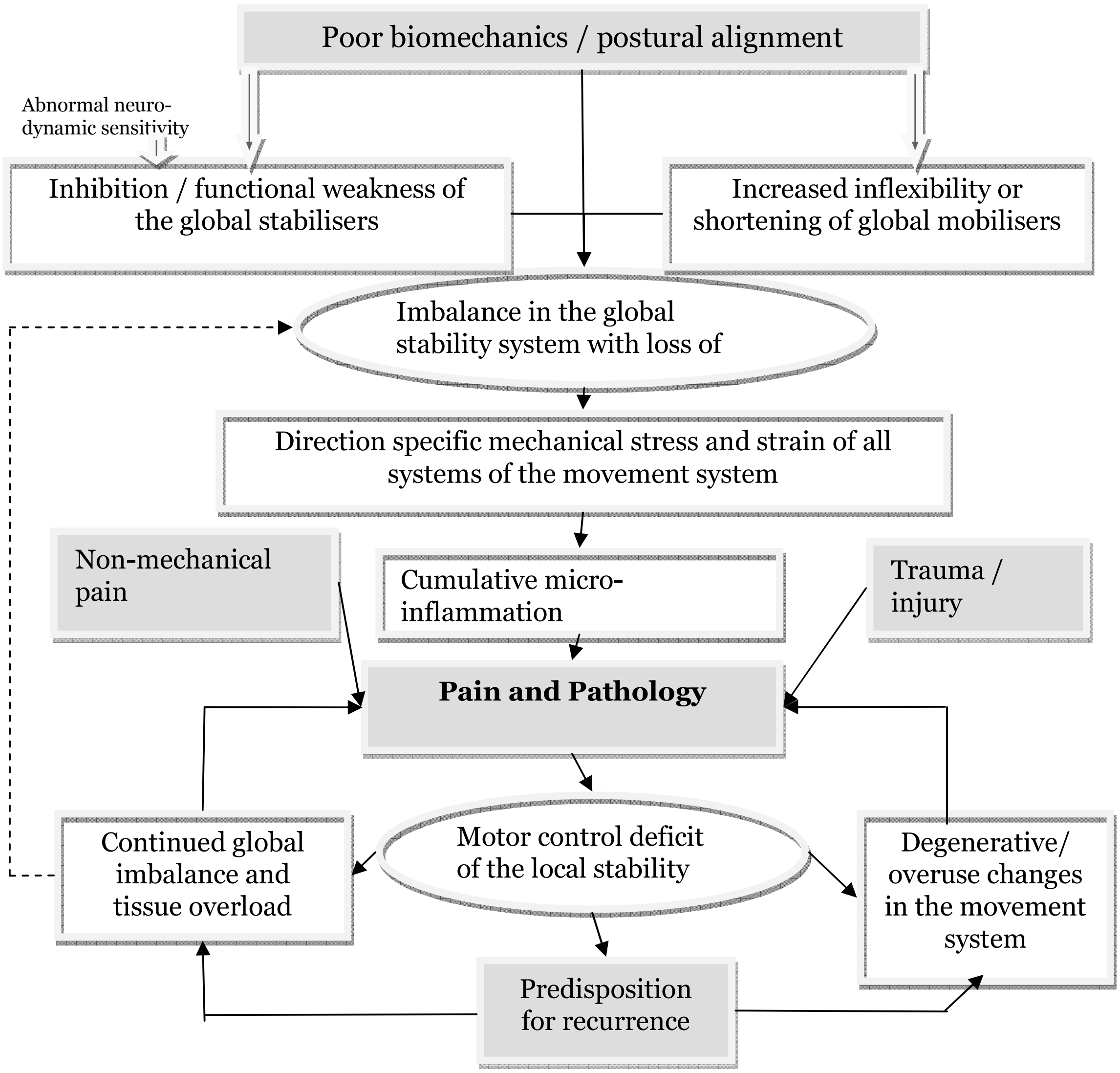


FIGURE 3: THE MODEL OF MOVEMENT DYSFUNCTION

(Comerford & Mottram, 2001:23)

Psychosocial factors have also been associated with changes in movement as optimal functioning within the active subsystems are regulated on a central nervous system/neural level as illustrated in Figure 2. Behavioural changes secondary to psychosocial influences may include fear-avoidance as an attempt to avoid pain by unloading injured tissue (Jull, Moore, Falla, Lewis, McCarthy & Sterling, 2015:56).

Vleeming and colleagues (1997) also included the integration of psychosocial factors such as cognitive emotion and awareness with structural and functional components of core stability. This report acknowledges numerous influences on the movement system and core-stability. However, for the purpose of this study only the active local- and global stability systems are explored as the muscle characteristics are most influenced and modifiable by the runners themselves.

2.2. THE LUMBO-PELVIC CORE AND RUNNING INJURY

The model of movement dysfunction (Figure 3) clearly embodies why lumbo-pelvic stability is clinically perceived to be a pivotal component of injury prevention and recovery from injury (Perrott, Pizzari, Opar & Cook 2012:1), yet recent research is severely lacking (Bruckner & Khan, 2012:224). Twenty-seven to seventy percent of recreational and competitive runners are expected to experience an injury within one year of running (Hreljac, 2005:651). Despite this significant prevalence of injuries reported by female runners, this population has not been a popular focus of lumbo-pelvic core research.

Female running is characterised by greater anterior pelvic tilt, axial rotations and lateral lumbo-pelvic flexion. Furthermore the hip complex presents with increased adduction/abduction range and stride length in comparison to male runners (Schache *et al.* 2003:114-116). Knee excursions also increase and vertical GRF are also twice that of walking. In the end, the altered muscle spindle input secondary to the biomechanics of running increases stress on the kinetic chain structures (Bruckner & Khan, 2012:66).

Increase in lumbar angulation has been associated with low-back pain due to the stress-increase on the intervertebral structures (Schache *et al.* 2005:140). The findings by Granata & Gottipati (2008:1267) are similar after a protocol to fatigue trunk extensors. TrA muscle is dominant in response to voluntary movement in lumbar extension (Sapsford, 2004:4). The additional multi-axial increase in excursions of the pelvic region during running results in increased demand from this as well as other local stability muscles. Delayed tonic recruitment in the presence of pain, injury or fatigue may then cause altered muscle activation patterns within the lumbo-pelvic core and lower limb (Figure 3).

The resulting sub-optimal distribution of increased vertical GRF within the kinetic chain causes imbalance and tissue overload putting the runner at risk for overuse injury (Kibler, Press & Sciascia, 2006:191; Comerford & Mottram, 2001:23). This is in agreement with the increase in knee stiffness found by Hamill, Moses & Seay (2009:271) in runners with low-back pain. The knee has been referred to as the predominant area of reported running injuries in female long-distance runners (Taunton, *et al.*, 2003:96). Research on female risk factors suggests neuromuscular mechanisms for knee injuries. These prospective studies, however few, established a loss of stability in female athletes by measureing properties of active proprioceptive trunk repositioning (Bliven & Anderson, 2013:516).

A decrease in isometric hip abductors, external rotators and lateral flexors as global core muscles are also suggested to be predictors of these lower limb injury in females due to their proximal muscle attachments (Leetun, Ireland, Willson, Ballantyne & McClay-Davis, 2004:932). This is in part supported by Nadler, Malanga, DePrince, Stitik & Feinberg (2000:92) who measured a difference in side-to-side symmetry of maximum extension of the hip in female runners with previous lower-limb injuries.

The isometric nature of testing of the global mobilisers in these studies did not display the endurance characteristics of these muscle groups within their functional role during running. Also, the integrated feed-forward activation of the local stabilisers with global functioning was also not considered or mentioned in this study. Still, this supports the notion of considering core-stability as a predictor of injury.

Other than lower limb injuries and low back pain (Hart *et al.*, 2009:261), pelvic pain and stress urinary incontinence are also common complaints of distance runners (Lynch & Hoch, 2010:483). Pelvic pain may present as local and/or referred pain in multiple sites in and around the pelvis, low back and thighs. Local stability muscle dysfunction has been related to pelvic pain with delayed or altered activation of the TrA, M. Multifidus, the PFM and diaphragm prior to initiation of limb-movement (Sapsford, 2008:8; Jull *et al.*, 2015:57).

Sacro-iliac pain is characterised by decreased anticipatory activation of the diaphragm and PFM (O'Sullivan *et al*. 2002:6) whereas sacro-iliac laxity is decreased by activation of the TrA (Richardson, Snijders, Hides, Damen, Pas & Storm, 2002:405). This is accompanied by a reduction in global core activity, more specifically the mm. Internal Oblique and Gluteus Maximus on the symptomatic side (Hungerford, Gilleard & Hodges 2003:1598). These studies all emphasise the significant contributions from the PFM to lumbo-pelvic stability and continence.

2.3. THE LUMBO-PELVIC CORE AND STRESS URINARY INCONTINENCE

The International Continence Society defines stress urinary incontinence (SUI) as involuntary leakage during effort or exertion, such as running, or on sneezing and coughing. Verifiable involuntary leakage must be synchronous with effort or exertion without detrusor muscle contraction during examination (Abrams, *et al*., 2003:38; Luber,2004:4). Albeit stress urinary incontinence does not fall under the specific classification criteria of a running injury, it can be biomechanically linked to injury. The psychosocial effect may also limit participation or alter movement (Jull *et al*., 2015:57). The pelvic floor functions as a musculoskeletal stability unit as described in the movement system (Sapsford, 2004:4).

The pelvic floor muscles are unique in terms of transverse load bearing capabilities. These muscles are predominantly tonic and present with 67-76% slow twitch fibres. Prolonged exercise such as long-distance running relies on this tonic activity as precursor for optimal phasic recruitment (Sapsford, 2004:5).

Stress urinary incontinence has been correlated with weak PFM, decreased PFM tonic activity, delayed PFM recruitment and abdominal muscle weakness. The active subsystem of the pelvic floor maintains continence. Conflicting views however exists on the PFM co-contracting with the local lumbo-pelvic active subsystem, significantly the TrA. Still, in terms of movement, Sapsford (2004:6) identified that an independent TrA contraction can ensure the required low-level pelvic floor activation needed for movement (Sapsford, 2004:6).

The model of movement dysfunction supports the plausibility of neuromuscular recruitment deficit of the lumbo-pelvic core resulting in SUI (Comerford & Mottram, 2001:23). The anticipatory characteristic of the local stabilisers will also not automatically normalize after inhibition (Comerford & Mottram, 2001:22). This, along with fatigue of the active subsystems, may explain the stress urinary incontinence reported by 28% of nulliparous elite female athletes, even though research suggests multiparous females to be more at risk (Bruckner & Khan, 2012:929).

Elite athletes are accepted to be holistically well-conditioned. However, 45.54% of elite female endurance athletes report SUI symptoms (Poswiata, Socha & Opara, 2014:94). Lynch & Hoch (2010:483) also report a staggering 35% of Olympic female athletes presenting with SUI. Consequently it raises the question as to the inclusion of the general lumbo-pelvic core and, more specifically, the pelvic floor and TrA in their conditioning protocols especially post-injury.

To summarise, similar to popular belief, the relationship between core-stability, running injury and SUI are supported by a number of studies. However, the evidence to concretely associate core stability deficiency to risk of running injury is still severely lacking.

2.4. NEUROMUSCULAR FATIGUE

The deficit in neuromuscular recruitment of core-muscles diminishes load transfer abilities and puts the kinetic chain at risk. This diminished facilitation may, amongst other reasons, be contributed to neuromuscular fatigue (Comerford & Mottram, 2001:16-17). Taking into account the biomechanics of running and the volumes of training, an increased demand is placed on the active lumbo-pelvic core in terms of endurance in order to resist the effect of fatigue. Functional endurance training such as the LSD has been shown to induce neuromuscular fatigue and bring about changes in terms of muscle characteristics (Meeusen, Watson, Hasegawa, Roelands & Piancentini, 2006:883).

Even though no scientific measure of fatigue of the core muscles was used for this research, this section will discuss the plausibility of neuromuscular fatigue of the core muscles as risk of injury within this research setting.

2.4.1. THE FATIGUE-MODEL

The cause of neuromuscular fatigue is multi-factorial in terms of impaired processes in multiple areas. Cairns, Knicker, Thompson & Sjøgaard (2005:9) acknowledged that fatigue can be considered task-dependent and therefore causes of fatigue can be narrowed down to the characteristics of the activity chosen to induce fatigue. During assembly of a model of fatigue for a sporting activity, certain guidelines (Figure 6) must be adhered to (Cairns *et al.*, 2005:10).

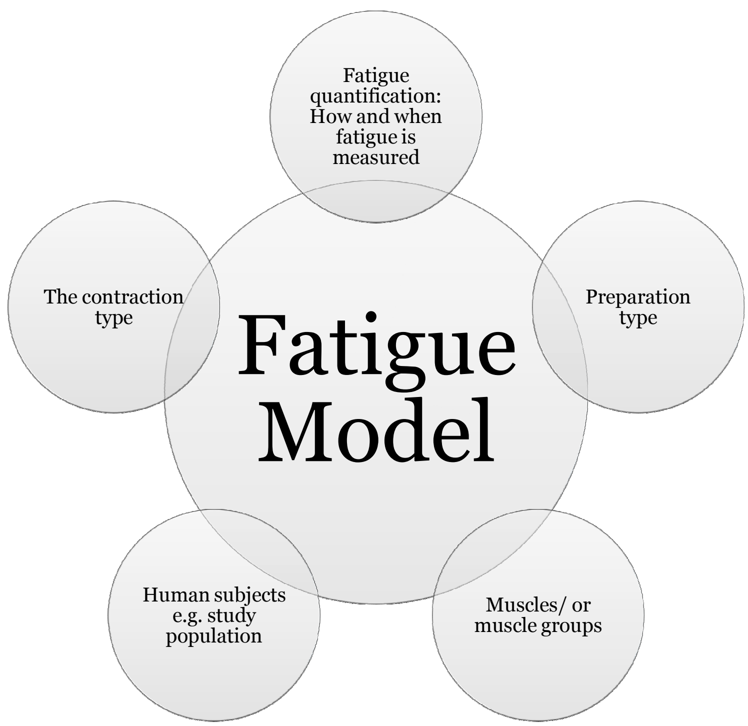


FIGURE 4: THE FATIGUE MODEL

(Cairns *et al.*, 2005:10).

In compliance with this model and for the purpose of this study any 24+ km LSD running task was deemed appropriate as functional activity to bring about fatigue. For the purpose of this research only the possibility of fatigue was explored in the interpretation and discussion of the changes in muscle characteristics as no formal measurement of fatigue was used during this research.

The LSD is prescribed in several running programs to promote muscular resistance to fatigue as it increases the capacity to maintain low-intensity, low resistance repetitive exercise by utilizing anaerobic oxidative and glycolytic systems to increase resistance to fatigue. The anaerobic oxidative system is predominant in the 24+km distances used for the purpose of this research (Kenney, Wilmore & Costill, 2012:222).

The LSDs used in this study is also in keeping with the distance that was used in the study investigating central and peripheral fatigue (Millet & Lepers, 2004:108). Also, these distances are in accordance with this study's definition of long distance runners.

2.4.2. CENTRAL & PERIPHERAL FATIGUE

Neuromuscular fatigue refers to the exercise-induced loss of performance. Evidence indicates a loss of maximal muscle force output from the beginning of prolonged exercise (Meeusen *et al.,* 2006:883). Central fatigue indicates the hypothesised decreased ability of the central nervous system to recruit motor units and is considered the main component of resulting fatigue (Millet, G., 2011:491). This alteration in the neural subsystems results in the loss in recruitment within the active subsystems and is attributed to the changes in metabolism and synthesis of noradrenalin, dopamine and serotonin. The latter causing loss of drive, lethargy and mood changes (Meeusen *et al.,* 2006:883).

Peripheral fatigue refers to the inability of recruitment of the muscle itself and its contribution to fatigue should not be underestimated (Millet, G., 2011:491). It includes the depletion of glycogen in the muscle that leads to a progressive loss in body fluids resulting in strain of the metabolic, cardiovascular and thermoregulatory systems (Meeusen *et al.*, 2006:883).

Millet & Lepers (2004:113) measured a central neuromuscular decrease in high-frequency torque of the quadriceps after a 30 km run, but a peripheral decrease could not be proven. This is in similar standing with the study by Petersen, Hansen, Aargaard, & Madsen (2007:394) after a 42 km run. Both studies identified the importance to test fatigue as soon as possible after activity to limit the effect of recovery.

The respective authors also mutually suggested the need to measure fatigue *during* activity in future studies. The significance of the quadriceps muscle as global load transfer and mobilising muscle in the lumbo-pelvic-hip complex warrants the inclusion of other proximal core stability muscles in future studies on neuromuscular fatigue (Millet & Lepers 2004:113).

In addition to neuromuscular knee-extension decreases, central power of plantarflexion remained decreased in neuromuscular activation for two days after the activity of fatigue. Peripheral and normal functional power did not normalise within five days (Petersen *et al.,* 2007:394-395). Theoretically, this can lead to a runner training in a state of fatigue for a minimum of five days after a 42 km run, predisposing the runner to overuse disorders.

Fatigue of the core musculature is associated with changes in lower limb kinematics. Gerlach, White, Burton, Dorn, Leddy & Horvath (2004:662) measured an increase in GRF caused by altered lower limb mechanics in fatigued female distance-runners. The study by Hart *et al.,* (2009:461) measured multiple hip and knee adaptation in jogging kinetics after fatiguing the lumbar paraspinal muscles. There is consensus in literature that fatigue of the lower limb can be caused on both a supra-spinal and/or peripheral level (Millet & Lepers, 2004:113; Petersen *et al.,* 2007:394).

As is the case with the majority of studies on core stability, Hart *et al.* (2009) focused on an isolated group of muscles within the core in one non-functional plane of movement. Running involves integrated muscle functioning in the frontal, saggital and transverse planes (Akuthota & Nadler, 2004:90). This again questions the non-functional and predominantly strength-biased methods chosen to assess the influence of fatigue on the integrated lumbo-pelvic stability structures in their entirety.

2.5. MEASUREMENT OF LUMBO-PELVIC CORE STABILITY

In the absence of gold-standard testing, a plethora of reliable and valid tests have been described in the assessment of the lumbo-pelvic core. A majority of these tests tend to only measure a single aspect of stability (Bliven & Anderson, 2013:516). This focus may be contributed to the classification and differentiation of muscles within the clinical setting (Bliven & Anderson, 2013:515).

The integrated nature of the subsystems to provide stability during running calls for multi-planar assessment of the endurance of the core musculature within functional, task-orientated positions.

Perrott *et al.* (2012:5) described qualitative criteria in rating core stability in runners using functional movements. Kibler, Press and Sciascia (2006:195) likewise proposed assessment in three-plane standing positions. Even though valid in construct and functionally applicable to this study, these qualitative ratings is still only reliant on examiner credibility and experience and cannot yield the reliable objective criteria required for use in profiling on endurance for runners. Furthermore, the prerequisite of the tonic motor recruitment of local stabilisers prior to initiation of movement requires differentiation of the local and the global muscle systems.

The assessment methods selected for this research study were tests frequently utilised within the clinical setting as is proposed for profiling (Comerford & Mottram, 2008). These valid and reliable tests are also illustrated in literature as suitable for test-retest purposes as is necessary in injury profiling.

EMG records the electrical activity of a muscle on a cathode-ray oscilloscope and has been described in the measurement of the TrA muscle and PFM. The EMG measures the activation/recruitment of the motor units (Grape, Dedering & Jonasson, 2009:395). EMG measurement of the PFM revealed an intraclass correlation coefficient (ICC; standard error of means) of 0.98 as found by Thompson *et al.* (2006:151). Another study showed good to high reliability of surface EMG on the PFM of healthy women (an ICC of 0-83-0.96 was determined).

Grape *et al.* (2009:369-399) recorded average and peak activity of 22.2 цV and 31.6 цV respectively in a population of healthy, nulliparous females. Aukee, Penttinen & Airaksinen, (2003:253) also documented mean values of 17.0 цV in incontinent subjects and 19.5 цV in continent participants. Thus, it is apparent that normative values fluctuate and as a result no normative value has been recommended thus far.

Surface EMG measurement of the TrA has been shown to replicate intramuscular EMG with high repeatability over a two week period. Reliability has been shown to be site dependent with high reliability for the TrA/internal oblique muscle site (Marshall & Murphy, 2003: 484-486).

Pressure biofeedback (PBU), also used to assess abdominal muscle function, is used to measure changes in pressure as the active stability systems attempt to stabilise the trunk. The unit transduces pressure from three air-filled chambers to a sphygmomanometer gauge. Movement of the lower limb changes the pressure within the unit that is displayed on the gauge. Any change more than 10mmHg above or below the baseline represents inability to control the trunk. The accuracy of the unit has been identified as ±3mmHg (Azevedo, Pereira, Andrade, Ferreira, Ferreira & Van Dillen, 2013:34).

In the original version of the test model of Jull, Richardson, Toppenberg, Comerford, and Bui (1993), the authors concluded that low load leg weight may be able to portray loss of active trunk stabilisation. The test is performed in supine and even though not functional in terms of running, the levels reflect the neuromuscular efforts of the active subsystems to stabilise and control the trunk in response to an increase in difficulty of low load kinetic chain activity (Azevedo *et al.*, 2013:34).

Repeatability of the PBU was established by Jull *et al.* (1993: 191-193). An average variation (AVU) of 9.3 was found over six (6) trials and considered acceptable. Furthermore, good intra-tester reliability (ICC 0.47-0.90) and acceptable construct validity was determined in the systematic review by De Paula Lima, De Oliviera, Pena Costa & Laurentinob (2011:102).

Other methods to test stability include the McGill assessments that are extensively used by clinicians. These endurance tests are functional and applicable to the purpose of this study as it asses synchronous stability and muscle endurance of the anterior, posterior and lateral musculature of the global system (McGill, Childs & Lieberman, 1999:943).

The anterior endurance is proposed to be more specific to the anterior musculature than the straight leg lowering test (Leetun *et al.,* 2004:929). There was very little variability in the latter measurement increasing the likelihood of Type II error. The McGill tests also show excellent reliability coefficients of > 0.97 for the repeated tests on five consecutive days and also after eight weeks (McGill, Childs & Lieberman, 1999:943).

The aforementioned tests demonstrates a battery of endurance tests for the active lumbo-pelvic core, for both muscles in singularity and functional muscle groups within the kinetic chain. The profiles created before and after the endurance task would not only display changes within the muscle characteristics, but also provide insight as to the applicability of these tests for risk-of-injury profling in this population as they are non-functional in terms of running.

However, the muscle profiles of the runners may be subjected to several intrinsic and extrinsic factors relating to increased risk of injury which would need to be taken into account with interpretation of the findings on the lumbo-pelvic core. For the purpose of this study, these factors were investigated by means of a questionnaire (see 3.6.2.).

2.6. INTRINSIC & EXTRINSIC RISK FACTORS OF OVERUSE INJURY

Overuse injuries result from repetitive musculoskeletal loading without sufficient rest (DiFiori, *et al.*, 2014:3). The combined sub-maximal loads result in fatigue beyond the tolerance of the associated structure as discussed within the movement system (Figure 3).

The multi-factorial causation model of overuse injury based on Meeuwisse *et al.* (cited in Bruckner & Khan, 2012:114) was adapted for the purpose of this study as illustrated in Figure 5. The adaptation encompasses predisposing risk factors that may render the female runner susceptible to injury and is relevant to the investigations done for this report.

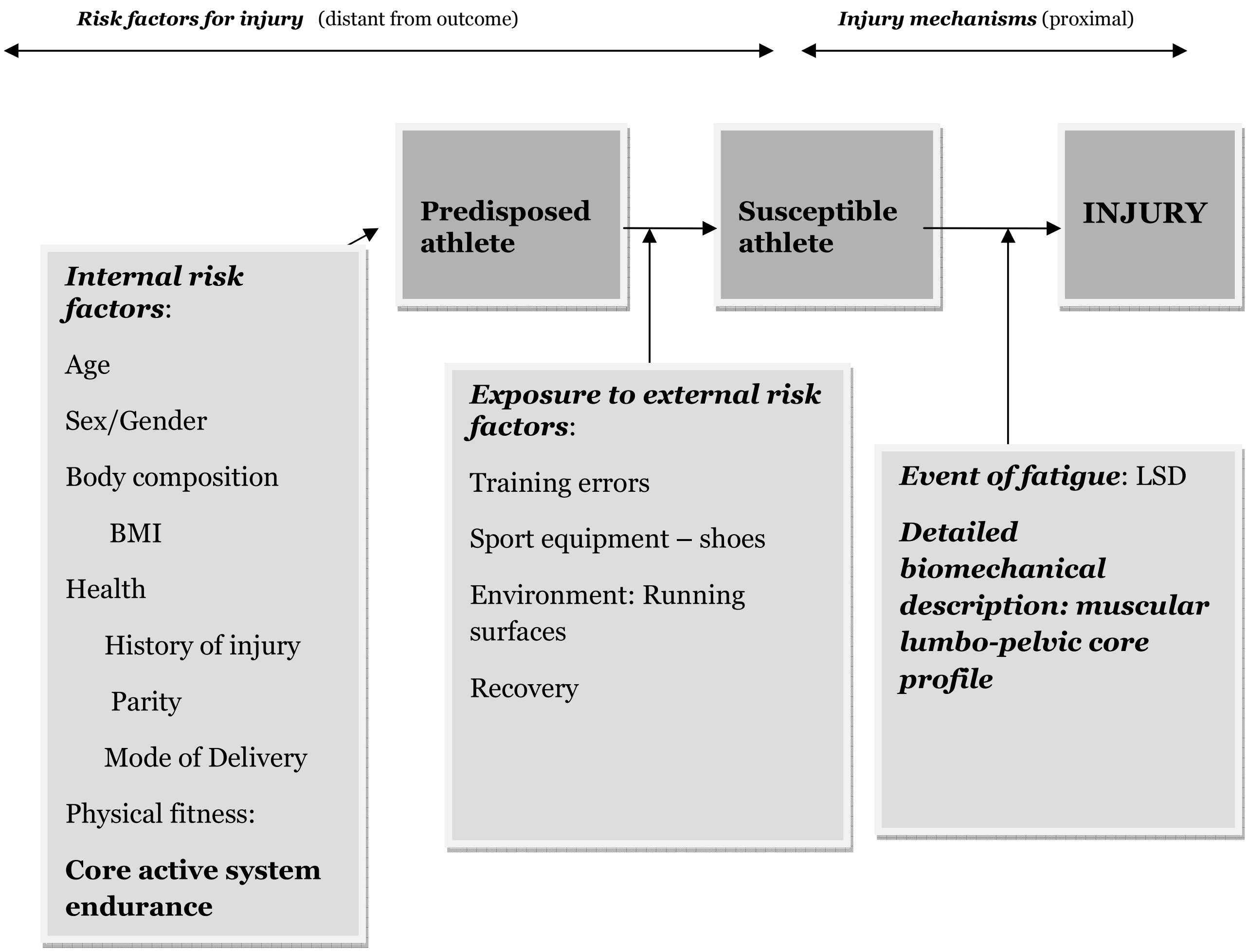


FIGURE 5: THE COMPREHENSIVE INJURY CAUSATION MODEL

Meeuwisse *et al*. (cited in Bruckner & Khan, 2012:114)

2.6.1. INTRINSIC/INTERNAL RISK FACTORS

Women are confronted with different activity-related issues across their lifespan. This section will discuss intrinsic factors that may influence the muscle characteristics assessed for this study. These factors pertain to the experienced female runner and are related to core-stability within the framework of the injury causation model.

2.6.1.1. GENDER AND BODY COMPOSITION

Gender characterises the anatomical and physiological differences between men and woman. Other than the mentioned biomechanical differences, the main sex difference influencing core stability is the effect of pregnancy and mode of delivery on the pelvic subsystems of the lumbo-pelvic core (Bruckner & Khan, 2012:910).

Pregnancy and vaginal delivery are major risk factors for weakened PFM, resulting in pelvic floor disorders including SUI. The hormonal changes in pregnancy alongside the soft-tissue and nerve damage are believed to increase this risk of SUI. Urinary continence dysfunction also increases in parallel with parity. Hence nulli-parity and cesarean section, in the short term, have a protective effect regarding pelvic floor disorders (Lukacz, Contreras, Nager & Luber, 2006:1258).

Also, a Body Mass Index (BMI) higher than 25 increases the likelihood of urinary incontinence (UI) (Wu, *et al.,* 2014:5). Subak, Richter & Hunskaar (2009:4) note a clear dose-response effect of weight on UI with about a 20% to 70% increase in the risk of UI with each five unit increase in BMI. Body mass index over 26 are also associated with running injury (Taunton *et al.,* 2003:272). The assessment of BMI is vital as it is a modifiable risk factor.

Finally, a significant correlation exists between previous injury and recurrent running injury in the same area (Van Gent *et al.,* 2007:475-476*)*. Another high quality systematic review on marathon runners also identified incomplete rehabilitation of previous injury as risk of injury recurrence (Taunton *et al.,* 2003:243). Rehabilitative measures taken for these injuries should include the core musculature to ensure optimal kinematics within the kinetic chain in return to sport (RTP). The specificity principles for RTP are discussed in paragraph 2.6.2.2. For the purpose of this research, previous surgery within the kinetic chain of the lower-limb is regarded as internal risk factor of injury as body composition and muscle physiology are altered after surgical intervention (Bruckner & Khan, 2012:25).

2.6.1.2. AGE

Logistic regression indicates female runners aged 50 years and older at an increased risk of injury (Taunton *et al.,* 2003:243). In terms of pelvic floor disorders, age-related loss of muscle cells and nerve density occur in the urogenital sphincter. The compression and anterior displacement of the mm. levator ani are also less pronounced in older women (Aukee, Penttinen & Airaksinen, 2003:256; Wu, *et al.*, 2014:6). Other than these pelvic floor disorders, muscle fiber dominance may alter due to ageing (Hoffman & Gabel, 2013:3).

Contrary to popular belief, more recent evidence describe the phenomena of the convertion from slow twitch to fast twitch fibre dominance with age and chronic musculoskeletal illness. This complex process is in part explained by mitochondrial deletion (Doria, Buonocore, Focarelli & Marzatico, 2012:12). Nevertheless, considerable evidence indicates that, with age, skeletal muscle properties still display sufficient adaptation to endurance exercise. Consequently, optimal core stability (including the PFM) could be upheld should the aging female runner maintain an endurance based training program.

2.6.2. EXTRINSIC/EXTERNAL RISK FACTORS

Under-conditioning, training errors, running surfaces and running shoes are relevant causative factors of muscular overuse and therefore suboptimal mechanics (Bruckner & Khan, 2012:25). Van Gent *et al.* (2007:475-476) also identified a significant association between running injuries and previous injury and the study also showed experienced runners to suffer from less injuries. However, the definition of an injury is still debated.

A runner, especially an uninjured runner, might not be compelled to add additional muscle conditioning to their exercise protocols. A runner may condition following guidelines from different sources ranging from popular magazines to professional exercise prescription. These guidelines may not include core stability and endurance as components of conditioning.

A similar hypothesis can be made in regards to training protocols and running shoes. In review of these assumptions a runner might be exposed to one or numerous of these sub-ideal scenarios and as such susceptibility to overuse is increased (Comerford & Mottram, 2001:4). No studies were found that investigated running injury within a multi-factorial setting as was attempted in this research.

2.6.2.1. MUSCLE CONDITIONING

There is a small differentiation between overuse and under-conditioning (Van Gent *et al.,* 2007:475). Very few researches had successful attempts in demonstrating a significant influence of core strengthening on low back pain and other injury or ailments. Nadler *et al*. (2000) reported a non-significant decrease in incidence of low back pain in subjects after a core strength program.

Akuthota & Nadler (2004:90) contribute this to the tendency of clinicians not to include the transverse plane in general exercise programs. Muscle endurance is vital for the core to resist fatigue during long-distance running. The two to four times maximum repetitions as used in the study by Nadler *et al*. (2000) did not exhibit endurance training characteristics

Clinicians generally agree on the motor re-education approach as the first stage in conditioning of the core-musculature, with emphasis on the TrA, mm. internal oblique muscles, mm. lumbar multifidus and the PFM (Sapsford; 2004:9). This correlates with the majority of core stability studies relating neuromuscular deficit to alter load transfer (Bliven & Anderson, 2013:516; Hodges & Richardson, 1997; Hungerford, Gilleard & Hodges, 2003). The physiological benefit of core exercises lies in the increased sensitivity of muscle spindles within the active subsystems. The risk of injury may be reduced secondary to the increased readiness of the kinetic chain for loading (Kenney, Wilmore, & Costill, 2012:220).

Conditioning/rehabilitation of the core's muscular system must take place in three stages for optimal conditioning. These stages commence with the motor skill training for predominantly type 1 slow motor units within the stability active subsystem. This stage of conditioning is crucial as core stability deficit has been identified in numerous occasions to be due to loss of neuromuscular control rather than strength deficit.

Also, in the event of pain or injury, the feed-forward properties of tonic muscles will not automatically return, but is correctable with exercise (Comerford & Mottram, 2001:23).

Recruitment of tonic muscles must therefore be in terms of timing, amplitude and endurance. Multiple sets of high repetitions as well as balance/physioball exercises are indicated as both modalities have been proven to increase spinal stability. This must then progress to include core strength-training of the global mobility system to further augment stability via optimal load transfer and to improve performance. Final progression should include functional activities and sport-specific training (Figure 6) (Behm, Drinkwater, Willardson, & Cowley, 2010:96).

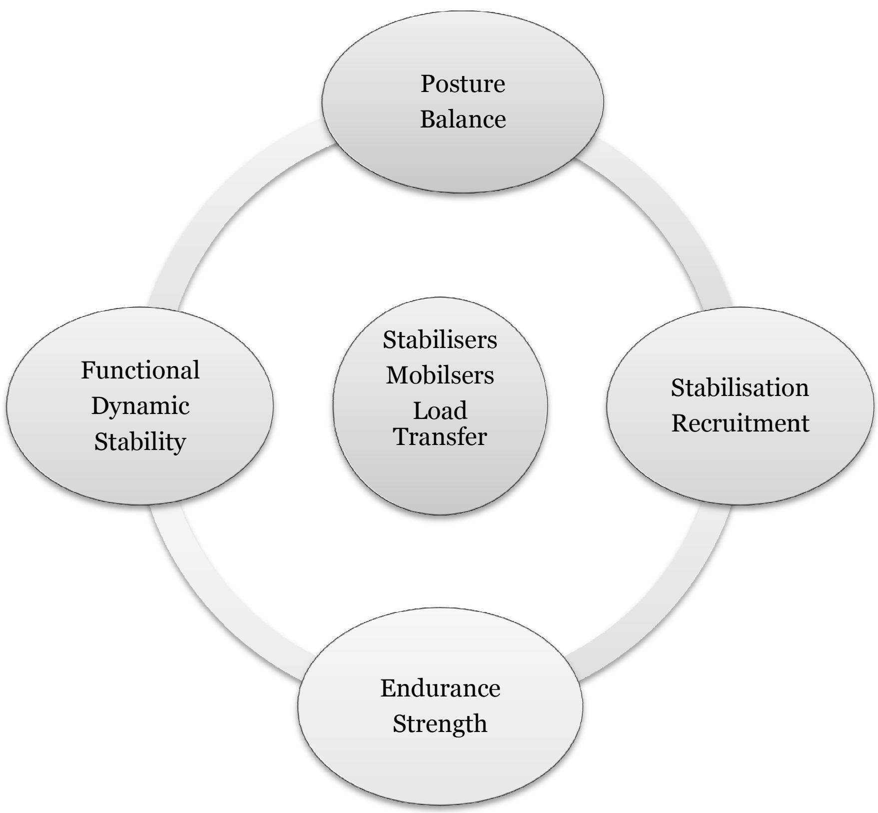


FIGURE 6: FUNCTIONAL CORE STABILISATION

(Bliven & Anderson, 2013:516)

Activation of the local, tonic muscles and diaphragmatic breathing must be incorporated prior to movement in all stages of conditioning. Diaphragmatic breathing increases isometric abdominal contraction that in turn enhances PFM activity and continence (Sapsford, 2004:7). Sufficient tonic activity ensures optimal postural awareness and positioning as stable base for movement.

Should conditioning and/or rehabilitation of a runner not include these stages with timely progression, muscle recruitment imbalance my lead to movement dysfunction and injury (Comerford & Mottram, 2001:9). Therefore, information on core muscle training and injury rehabilitation was gathered from participants in this study.

2.6.2.2. TRAINING ERRORS

Training errors is widely discussed as a significant contributor to overuse injuries. A systematic review of good quality studies by Van Gent *et al*. (2007:475) concluded that greater training distances per week predispose overuse knee-injuries. Though not significant, Nielsen *et al*. (2012:71) supported an association between mileage increase and injury. Conversely, Rasmussen, Nielsen, Juul and Rasmussen (2013:119) suggested mileages above 30 kilometers the week before a marathon to decrease risk of running injury. Nielsen *et al*. (2012:70) proposed two to five running sessions per week and a weekly increase of mileage of no more than 10% to be most favourable in preventing injury.

Other than the principle of overload as discussed above, specificity refers to directing training to increase performance within the athlete's given sport (Bruckner & Khan, 2012: 130). Sport-specific training for runners includes continuous training such as the LSD. The LSD is a form of low-intensity endurance training structured to affect the anaerobic oxidative and glycolytic systems to increase resistance to fatigue. During distances higher than 5 kilometres, the anaerobic oxidative system becomes predominant. A 90% emphasis is placed on this system during a 42.2 km marathon. The focus during an LSD is on distance and the speed and should be substantially lower than race pace (Kenney, Wilmore, & Costill, 2012:220).

A third principle to consider is periodisation Overuse injury is a considerable risk with extreme distances, increased pace and absence of periodisation (Kenney, Wilmore, & Costill, 2012:222). Periodisation ensures complete physical and mental recovery after a runner's competitive season. To lessen the risk of injury, a time frame of four to six weeks of decreased volume and intensity must be introduced (Bruckner & Khan, 2012:128).

Despite these contrary views and conflicting evidence on training volume, pace and intensity, a sudden sharp increase to any training component is associated with the cycle of overuse (Bruckner & Khan, 2012:114).

2.6.2.3. RUNNING EQUIPMENT (SHOES) AND ENVIRONMENT (SURFACE)

Running shoes are also an important external causative factor of overuse as it is the easiest introducible change the runner can make. Even though the study by Hreljac (2005:657) concludes that a biomechanical evaluation with different shoes is necessary for optimal biomechanics, it is not the most feasible approach due to poor accessibility.

As alternative, this study supports numerous other authors in suggesting a comfortable fit and sufficient cushioning. Two good quality studies have associated running injuries in females with shoe change after three (3) months of use to ensure optimal cushioning and support (Taunton *et al.* 2003:243; Van Gent *et al.* 2007:475). This, alongside refraining from running on excessively hard, soft or cambered surfaces, will minimize the load of the GRF on to allow for proper transmission (Hreljac, 2005:657). A sudden change in shoe and/or surface also interferes with load transfer due to adaptation within biomechanical muscle activation patterns already set within the central nervous system pathways (Bruckner & Khan, 2012:25; Kibler, Press & Sciascia, 2006:3). The subject of optimal running shoes is however still strongly debated.

2.6.2.4. RECOVERY

The prolonged duration of long-distance running predispose exercise-induced muscle damage. This is due to the repetition of especially the eccentric component of the stretch-shortening cycle (SSC). The SSC is an important component of muscle force production in terms of reflexive storage and utilisation of elastic energy. Delayed onset of muscle soreness (DOMS) is the most prominent clinical symptom and research-marker of exercise-induced muscle damage (Byrne, Twist & Eston, 2004:50).

Continued endurance exercise used in running training programs has been shown to elicit central fatigue within the kinetic chain (Millet & Lepers, 2004:113). Endurance exercise in the presence of muscle damage is characterised by additional loss of muscle function and SSC within the quadriceps and calf muscles. This may elicit a vicious cycle by further contributing to the fatigue induced by regular endurance training (Byrne, Twist & Eston, 2004:58).

Neuromuscular fatigue induced by exercise also impairs proprioception, especially after eccentric exercise (Byrne, Twist & Eston, 2004:58). The altered perception of movement and joint positioning ignites the dysfunction of movement, predisposing injury (Figure 3).

The objectives of recovery are therefore aimed at full restoration of function by means of recovery of neuromuscular fatigue and muscle soreness. Research on the various methods of recovery are however limited. Petersen *et al.* (2007:394-395) equate the recovery from central and peripheral fatigue after a marathon distance to be two to five days. Runners generally engage in active recovery such as cross-training that includes swimming and cycling (Bruckner & Khan, 2012:138). It would be fair to infer that a runner should actively recover for at least two days to reduce risk of injury.

3. CONCLUSION

Running is a popular and beneficial habitual and competitive sport. Both in literature and in clinical practice female long-distance runners frequently present with overuse lower-limb injuries, spinal- and pelvic pain and ilio-gynaecological issues such as stress urinary incontinence. However, despite the high prevalence of injury very little research focuses on this population.

Clinicians readily regard optimal lumbo-pelvic-hip complex (core) stability crucial to injury prevention. This evidence-based review argues that, although limited in evidence, neuromuscular recruitment of proximal stability muscles within a movement system proves ideal for controlled lower limb kinematics as well as for optimal load transfer to the torso and upper limb. Muscle endurance, rather than strength is advocated for core-stability and numerous internal and external factors predispose core dysfunction and overuse injury.

Lastly, a battery of valid and reliable tests is needed to compile profiles for both single muscle groups as well as integrated active components of the core. Profiling could potentially portray that a runner has a reduced risk of injury when her core muscles display sufficient recruitment and resistance to fatigue in performing a functional endurance task. This ability to maintain optimal movement in the face of fatigue entails numerous intrinsic and extrinsic factors.

The research aims, questions, research population and methodology are discussed Chapter 3. Chapter 3 further highlights the ethical considerations that posed an additional challenge for this research.

CHAPTER 3

METHODOLOGY

This research investigated lumbo-pelvic core muscle characteristics of female long-distance runners by means of profiling. This chapter discusses the research aims, research questions, study design, study population and sample. The ethical considerations, instrumentation and methods used in the pilot study and in the research data collection are also illustrated.

3.1. RESEARCH AIMS

The primary aim of this study was to compile and discuss profiles that demonstrate the changes in individual core stability muscle characteristics of female long-distance runners after a functional endurance task. The discussion on the changes within the profiles reflected the influence of a functional activity on the stability base of the running movement system in terms of risk of injury. The secondary objective was to identify intrinsic and extrinsic risk factors that influence the core musculature profiles and may predispose movement dysfunction and injury.

3.2. RESEARCH QUESTIONS

3.2.1. What changes in muscle characteristics of the active stability subsystem of the core are reflected in the individual profiles of female long-distance runners after a functional endurance task?

3.2.2. Can the changes relate to risk of injury in terms of movement dysfunction?

3.2.3. What intrinsic and extrinsic factors are present that may influence core musculature and predispose injury?

3.3. STUDY DESIGN

This study was a quantitative, descriptive cohort analytical design (Figure 7). The descriptive characteristics of the group of female long-distance runners included demographic information that also formed part of the internal and external causative factors of overuse injury. This was used to determine the prevalence of these injury-related factors within the cohort.

The changes in the baseline core muscle characteristics/profiles were analysed as it presented within the post-exercise profiles. The advantage of this analytical approach was to observe possible mechanisms/reasons for change within the profiles and how it may relate to overuse injury. The disadvantage however lied within the duration of participation needed to determine the outcomes of the research and its resulting limitation in sample size (3.4.3.).

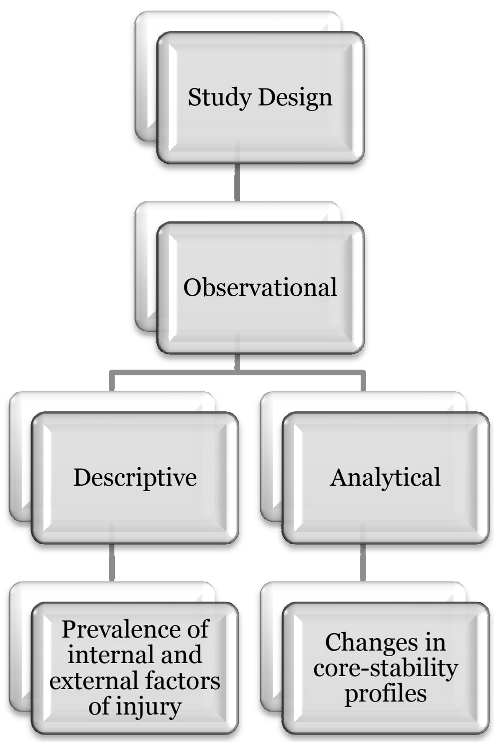


FIGURE 7: STUDY DESIGN

3.4. POPULATION AND SAMPLING

3.4.1. TARGET POPULATION

The population consisted of female long-distance runners in Bloemfontein registered with Athletics Free State (AFS) a division of Athletics South Africa. The population size is further discussed in 3.4.3.

3.4.2. INCLUSION AND EXCLUSION CRITERIA

In accordance with the definition of a long-distance runner, only female runners with weekly training mileage of 30+ kilometres were considered for this study. Participants also must have completed a 42 kilometer marathon within the qualifying time of five hours within the last twelve months. This ensured that participants were 18 years of age and older and had experience in long-distance training. Runners with sufficient literacy to complete a questionnaire in English or Afrikaans were eligible.

Novice runners who only commenced with long-distance running within the last twelve months were excluded as literature proposes additional running-related injury risks for that population (Nielsen *et al.,* 2012:70). Pregnant runners and runners within six weeks post-partum were not eligible due to the physiological influences on the muscle characteristics investigated in this study (Henn, 2014). Any injury that prohibited usual and regular training for one week (seven days) prior to the study excluded the runner from participation.

3.4.3. SAMPLING: SIZE AND METHOD

The study analysed and discussed the changes and risk factors pertaining to each individual participant's profile. As this minimised selection bias, a convenience sampling method was used.

Limitations in determining sampling size were contributed to the registration of runners with AFS. Runners are licensed if registered with an AFS affiliated running club. Registration however does not distinguish between long-distance running and shorter distance running. The running clubs, and not AFS, have the statistics on the number of female runners.

The researcher contacted the affiliated running clubs in Bloemfontein both telephonically and by e-mail. Only three running clubs gave feedback on female runners in general and were not able to provide the number of female long-distance runners. Thus, due to insufficient feedback, the size of the target population could not be accurately determined.

The researcher communicated the specifications of the study to the chairpersons of the running clubs by telephone and by email. An information letter (Addendum A) was forwarded to their female members. Only three running clubs agreed to the researcher meeting with their runners prior to a club run to invite the female runners that met the inclusion criteria to participate in the study.

Fifteen (15) female long-distance runners who met the inclusion criteria volunteered and took part in the study.

3.5. ETHICAL CONSIDERATIONS

This study was approved by the Ethics Committee of Health Science of the University of the Free State (Addendum B). The execution of the study was as stipulated in the approved protocol.

Information regarding the study, recruitment of participants and all measurement were conducted either in Afrikaans or English as preferred by each individual participant.

Each participant received an information letter (Addendum A) and gave written consent (Addendum C) to partake in the study. Both documents confirmed voluntary participation, stated that measurements may be refused and informed participants that they may withdrew from the study at any time.

To maximise the safety of the participants, runners from the same club were grouped together in order to use the long slow distance runs of their affiliated running club.

Anonymity and confidentiality were maximised in all aspects of the study. Complete anonymity was however not possible due to physical measurement and to ensure that the participants had access to their individual results after completion of the research. Due to the invasive and exposing nature of the EMG testing (3.6.5.1.), the testing was conducted in an enclosed room with a door.

The vaginal electrode was also inserted and removed by the participants themselves after careful instruction by the researcher (3.6.5.1.). The vaginal electrodes were also discarded following procedures for medical waste.

The research team members signed a confidentiality agreement (Addendum D). Data will be kept for five years after completion of the study and kept safe by the researcher in a locked safe. The data will be burnt after five years.

Outcomes of the study included feedback to each participant on their own core profile and injury risks and publication in an accredited journal. Feedback was however to each participant on her own profile and injury risks only and no data used for publication would risk anonymity.

The researcher was suitably qualified and covered against malpractice. The researcher was also trained in emergency first aid and cardiopulmonary resuscitation (CPR) should any problems had arose during the study.

The National Research Foundation provided funding for this study, but without influence on any aspect of thereof. All other costs were carried by the researcher.

3.6. DATA COLLECTION AND MEASURING INSTRUMENTS

3.6.1. RECRUITMENT/INFORMATION LETTER AND INFORMED CONSENT

The information letter (Addendum A) served as information document and was compiled as per the guidelines of the Ethics Committee of the Health Sciences of the University of the Free State (The University of the Free State, 2012). The letter included the title of the study and the information on the persons responsible for the research including the contact person for the Ethics Committee.

The aim and objective of the study were also explained in the document in layman terms followed by the procedures and instrumentation used during data collection. The duration of involvement of the participants in the study was stipulated along with the ethical considerations for the study as discussed in section 3.5. The letter was sent to each participant via email and a signed hardcopy was provided on the day of measurement.

Each participant signed informed consent (Addendum C). This document provided an overview of the received information letter and was signed by both participant and researcher on the day the data-collection was done for that participant.

3.6.2. QUESTIONNAIRE

The questionnaire (Addendum E) was formulated to identify the possible intrinsic and extrinsic factors for each participant that may influence the active core system as well as predispose injury. These factors included biographic and demographic variables that, in turn, also describe this long-distance running population. Table 3 summarises the formulation of questions to represent certain intrinsic and extrinsic factors identified in literature.

TABLE 3: VARIABLES WITHIN THE QUESTIONNAIRE

Question	*Variable/s*	*Internal factor*	*External factor*	*Other*
Age	Age	√		Biographic
Level of Participation	Level of Participation			Demographic
Previous surgery	Previous surgery involving core and lower-limb chain	√		
Co-morbidities	Co-morbidities influencing optimal muscle activity	√		
Pregnancy/birth history	Mode of Delivery Parity	√		
Injury	Previous injury influenced by the core and lower-limb chain	√		

Question	*Variable/s*	*Internal factor*	*External factor*	*Other*
Injury Rehabilitation	Isolated or integrated exercise incl./excl. the core	√	√	
Running shoe	Type of running shoe Replacing the shoe		√	
Running surface	Alternating running surface		√	
Weekly mileage: • *6/52 prior to competition* • *1/52 prior to research* • *In-season* • *Off-season*	Training volume Specificity Training volume Training volume Periodisation		√ √ √	Influence data
Mileage increase	Training volume		√	
Days per week running	Running frequency		√	
Running Pace	Training pace compared to race pace		√	

Question	*Variable/s*	*Internal factor*	*External factor*	*Other*
Training				
• *Cross-training*	Recovery/load ↓		√	
• *Conditioning*	Core conditioning		√	
	Pelvic floor exercises			
	Specificity			
• *Source*	Source of exercise		√	
	Supervised training			

The questionnaire was formulated in Afrikaans and English and face validity was determined on review by the study leader and evaluation committee assigned to this research. The questionnaire was also piloted (3.6.6.). Each participant was assigned an identification number used on all documentation and on both the questionnaire and baseline dataform. Each participant completed a questionnaire in the language of their choice directly after the baseline measurement. The researcher (R1) was present to address any uncertainties regarding questions in the questionnaire.

3.6.3. DATA FORM

The dataforms (Addenda F&H) were drafted to reflect a profile of the active core subsystem muscle characteristics. Both baseline and post-exercise forms consisted of EMG data in цV, pressure biofeedback data in levels and functional endurance in seconds.

The baseline form (Addendum F) also included the BMI calculation of each participant as internal factor influencing continence and fatigue. The post-exercise form (Addendum H) also displayed the LSD completed by each participant in order to discuss each profile in terms of the specific distance and to determine the average distance used in this research.

3.6.4. DATA COLLECTION

3.6.4.1. METHOD OF DATA COLLECTION

The duration of the test battery and the testing of groups necessitated a research team. The research team consisted of the researcher (R1), a physiotherapist (R2) experienced in pressure biofeedback testing and a biokineticist (R3) with ten years of experience in McGill testing procedures. The researcher was responsible for EMG testing procedures and measurement of the height and weight, R2 for pressure biofeedback testing and R3 for the McGill endurance tests.

On occasion, R1 conducted all measurements when one or two participants were tested. A one hour training and simulation session was done with the research team to ensure reliability of measurement. All testing procedures have been shown to have good- to excellent intra-tester reliability as discussed in section 2.4. Therefore, post-exercise testing was conducted by the same researcher who performed baseline testing for each participant.

All measurement was done at the researcher's physiotherapy practice. Appropriate consent was obtained from the owner of the premises and the researcher's associate. Participants were grouped within club affiliation in order to use club and group runs of 24+km as functional LSD run for this research. This was to maximise the safety of the participants who prefer LSD training in early mornings. Individual testing was also done as participants were available for measurement. These individuals also completed an LSD as part of a club or group run.

Any LSD of 24 kilometers was used as a functional endurance task. This and greater distances have been shown in literature to induce fatigue (2.4.2.) and are distances used in long-distance running training programs to promote endurance. The self-reported distance of each participant's LSD was recorded on the post-exercise dataform (Addendum H).

There was no specific order to testing procedures due to practicality. Within the group setting a participant was tested by each researcher as soon as the former test was completed. Individual testing was also not performed within any particular order.

Post-exercise measurement was performed as soon as possible after completion of the functional LSD, but not after thirty minutes, to minimise recovery. This cut-off value serves as minimum timeframe of prolonged fatigue (Millet & Lepers, 2004:105). Any time discrepancies in post-exercise testing between participants within thirty minutes had no influence on the interpretation of data as no comparisons were drawn between subjects.

3.6.5. TESTING PROCEDURES

3.6.5.1. ELECTROMYOGRAPIC (EMG) MEASUREMENT: PELVIC FLOOR

This method not only measures intra-vaginal muscle-activity during contraction of the pelvic floor muscles (PFM), but also the resting tone of the PFM (Lang, Brown, & Crombie, 2007:126). The test was performed in the dorsal lithotomy position using the Neurotrac™ Myoplus 2. A periform intra-vaginal probe served as surface electrode. The opposing electrodes make contact with the lateral vaginal walls after insertion. Optimal contact and positioning of the probe in relation to the PFM were maintained by the participants manually supporting the EMG probe (Thompson, O`Sullivan, Briffa & Neumann, 2006:270).

Each participant was instructed on correct self- placement of the intra-vaginal probe. After secure placement, the participant was asked to maximally contract the PFM by performing a "draw in and lift" action of the PFM. The test was repeated three (3) times with a ten second rest between each trial (Thompson, O`Sullivan, Briffa, & Neumann, 2006:151). The Neurotrac™ determined the average of the three readings. The average was recorded on the data form.

3.6.5.2. ELECTROMYOGRAPIC (EMG) MEASUREMENT: TRA

The internal oblique muscle with the underlying TrA surface-EMG was used to measure motor recruitment of the TrA. The superior anterior iliac spinae (ASIS) was joined by a line and disposable electrodes placed along the line immediately medial to the ASIS. This TrA/m. internal oblique placement is highly reliable to represent TrA motor activity (Marshall & Murphy, 2003: 484-486).

The participants were instructed to contract/activate the TrA in a dorsal lithotomy position by contracting their lower stomach muscles by a“navel-to-your-spine” pulling action. The Neurotrac™ Myoplus 2 recorded (3) three contractions maintained for ten seconds with ten seconds rest between efforts. The recorded average was captured on the dataform. A reference electrode was placed on the M. Gluteus Medius (Sapsford, Richardson, & Stanton, 2006:220; Sapsford, Richardson, Maher, & Hodges, 2008:174).

3.6.5.3. PRESSURE BIOFEEDBACK

A pressure biofeedback unit (PBU) was used to measure changes in pressure as the local and global lumbo-pelvic muscles aim to stabilise the trunk during low load limb movement. The pressure cuff was placed under the lumbar lordosis and inflated to 40mmHg. Participants were asked to breath regularly and the inflation adjusted to accommodate breathing. Changes greater than 10mmHg are indicative of sub-optimal lumbo-pelvic control (2.5.).

The participants were given instruction on maintaining the pressure on the gauge while performing different lower-limb activities. Each level was only described after the previous level was successfully completed. Each activity represents a level of lumbo-pelvic stabilisation (Mills, Taunton, & Mills, 2005:62-65). Participants were allowed three trials on each level, but were progressed to the next level after any successful stabilisation of movement. Scoring was at the highest completed level (Addendum G) where the instructed task was completed with a change of less than 10 mmHg on the PBU with a normal breathing pattern (Roussel, Nijs, Truijen, Vervecken, Mottram, & Stassijns, 2009:1070). Image 1 displays the starting position and minimum cut-off level 1. Test instruction is described in full in Addendum G.

IMAGE 1: PRESSURE BIOFEEDBACK TESTING STARTING POSITION/ LEVEL 1

Image used with the permission of the model.

3.6.5.4. FUNCTIONAL TESTING: ANTERIOR MUSCLE-GROUP

The test was performed seated. Participants' backs were supported on a standardised 60° wedge as measured from the horizontal plane. The participants' hands were crossed over their chests and their feet were secured under a strap. The instruction was to maintain the position while the supporting wedge was removed 10 centimetres (Image 2). A stopwatch was used to measure the time in seconds that the participants were able to maintain the 60° angle. The test ended when the researcher observed a drop in the subject's angle below the 60° threshold.

IMAGE 2: ANTERIOR MUSCLE-GROUP TESTING

Image used with the permission of the model.

The test was repeated three (3) times with a resting period of two (2) minutes in between trials (Earl & Hoch, 2011:157). The test results and average was recorded on the data form. The average was used for data analysis. The test was repeated after the longrun and the measurement again recorded as stipulated above in the post-exercise dataform. (Addendum H).

3.6.5.5. FUNCTIONAL TESTING: LATERAL MUSCLE-GROUPS

This test was performed after a minimum of two (2) minute resting period after completion of the previous functional test (Earl & Hoch, 2011:157). Participants were positioned in side-lying on a treatment mat on the floor. The top of the bottom foot and the hips were positioned in zero (0) degrees of flexion. The participants were then asked to lift their hips off the ground, using only their feet and elbow as support. The uppermost arm was held across their chest with the hand on the opposite shoulder. This position is known as the side-bridge (Image 3).

IMAGE 3: LATERAL MUSCLE-GROUP TESTING

Image used with the permission of the model.

A stopwatch was used to record the total time the subjects were able to lift the bottom hip from the table and maintain the straight posture. The measurement was repeated three (3) times, with the average recorded on the data form for analysis. Each trial was followed by a rest period of two (2) minutes as suggested by Earl and Hoch (2011:157).

McGill *et al.* (1999) reported no significant difference between right and left side-bridge. The study by Leetun *et al.* (2004: 929) also applied this in their cross-sectional comparative study. Since the purpose of this study was to compile a holistic core stability profile, the testing was done on both the right and left side and recorded. The dominant side was tested first in order to compare individual baseline and post-exercise results.

The test was repeated after the LSD and the average recorded on the post-exercise used for analysis (Addendum H).

3.6.5.6. FUNCTIONAL TESTING: POSTERIOR MUSCLE-GROUP

A modified Biering-Sorensen test was used as described in the study by Leetun *et al.* (2004: 928) (Image 4). This measurement was performed following a two (2) minute resting period from the previous functional test (Earl & Hoch, 2011: 157). Participants' pelvis and legs were strapped securely to a plinth. The torso was supported by each participant's hands on a bench placed in front of the plinth.

IMAGE 4: POSTERIOR MUSCLE-GROUP TESTING

Image used with the permission of the model.

The participants were instructed to maintain the horizontal spinal position. A stopwatch recorded the time the participants were able to maintain the position until they touched the bench. The measurement was repeated three (3) times and the average recorded on the data form. Each trial was followed by a 2 minute resting period (Earl & Hoch, 2011: 157). Measurement was repeated after the longrun and the average measurement recorded on the post-exercise dataform (Addendum F).

McGill *et al.* (1999) published normative data for a healthy young individuals for each of the functional tests (Addendum I). However, this research compiled profiles for runners of a variety of ages and each participant provided individual baseline measurements prior to the activity to be compared with individual measurement directly after the run. Therefore, no cut-off value was proposed for this study.

3.6.5.7. BODY MASS INDEX

The height and weight was measured standing erect and barefoot. Each participant's height was recorded to the nearest centimeter as measured using a stadiometer. Weight was measured using a standardised digital scale. The weight of participants was recorded to the nearest 0.1 kg.

The BMI was calculated using Quetelet's formula of kg/m^2 and recorded on the data form. Measurement was preferred to self-reported BMI as only 5 % of self-reported BMI has been found to be accurate (Fattah, Farah, O'Toole, Barry, Stuart & Turner, 2009: 33).

3.6.6. PILOT STUDY

The pilot study was conducted on four participants. Testing procedures were as described in 3.6.5.. The data obtained from the pilot study was used in the data analysis as the pilot study did not result in any changes that may influence data. The only change introduced was to perform baseline testing on the day prior to the functional task.

Testing directly prior to the LSD required grouped participants to be tested at 04h00 am. For safety and practical reasons baseline testing was performed on Friday afternoon given that participants did not engage in any activities that may result in fatigue. This change did not influence the outcome of this study since profiling is individualised and no comparative data analysis was performed for this study.

3.7. MEASUREMENT AND METHODOLOGICAL ERRORS

The use of a battery of testing procedures prior to a prolonged functional activity posed several methodological and measurement errors. The use of invasive testing procedures (3.6.5.1.) necessitated a private testing area both at baseline and post-exercise. Each participant was responsible for the placement of their intravaginal electrode. The researcher gave proper instruction prior to the procedure and no errors were displayed by the Neurotrac ™ Myoplus 2.

The use of clubruns for safety reasons also required participants to travel between those areas at a distance from the area where measurement took place. The researcher aimed to limit the effect of recovery on post-exercise data by instructing participants to return for post-exercise measurement within thirty minutes. This timeframe is considered to not result in recovery that might have negatively affected data (3.6.4.1.). To further limit the effect of recovery on measurements, the researcher made use of research assistants (3.6.4.1).

The duration of baseline testing prior to the prolonged functional task necessitated baseline measurement to be performed on an alternative day prior to the day of completing the LSD. Participants were all measured at baseline on afternoons prior to the LSD after verbally reporting no activity during the day that might have elicited significant fatigue e.g. running or gym. The mileages prior to the baseline testing were recorded on the questionnaire to determine noticeable differences in exposure to fatigue (Chapter 4, Graph 4). Since no within group comparisons were made, these influences would only have had an effect on the individual runner and the focus and discussion of the research were on individual profiles.

To ensure reliability within the research team, all members were responsible for only one testing procedure. Furthermore, only tests with good- to excellent intratester reliability were used (2.5.) and all other measuring instruments such as the scale, stadiometer and stopwatches were standardised. The research assistants were also trained and familiarised with the research in general (3.6.4.1.) On occasion unforeseen circumstances (such as availability of participants or the research assistants not being available) forced the researcher to do all measurements. Measurement was then limited to two participants and the participants' baseline measurements were in succession.

The LSDs were also completed on different times to ensure post-exercise measurement sooner than thirty minutes to prevent overlapping in post-exercise measurement.

No specific order could be allocated to the testing procedures in order to manage time efficiently, especially post-exercise to limit recovery. This was not expected to significantly influence this research as it referred changes to the *integrated* active stability profiles.

The questionnaire was completed after baseline measurement and in the presence of the researcher should questions have arisen. Each participant completed a questionnaire within the language of their choice as stipulated within the inclusion criteria. Finally, all methods and instruments underwent piloting (3.6.6.).

3.8. DATA ANALYSIS

The researcher coded the questionnaire and respective dataforms after completion of post-exercise measurement. The data was then captured on Microsoft Excel and submitted to the Department of Biostatistics at the University of the Free State for piloting and for final analysis.

Data analysis included summaries of numerical variables by means of standard deviations, medians and percentiles. The categorical variables were summarised by frequencies and percentages. Within group changes were evaluated using appropriate test- and confidence intervals for paired data.

The graphs, tables and figures drawn from the data are displayed in Chapter 4.

3.9. CONCLUSION

A cohort of fifteen experienced female long-distance runners was measured to compile profiles that summarised their active core stability systems as well as the changes resulting from a functional endurance task. The characteristics of the muscles were measured using functional tests, EMG and pressure biofeedback both at baseline and after an LSD of any distance greater than 24km. A questionnaire identified the intrinsic and extrinsic influences that may both predispose injury and influence the core characteristics. The analysis of the descriptive findings is displayed in Chapter 4.

CHAPTER 4

RESULTS

The purpose of this study was to compile, compare and discuss baseline and post-exercise profiles of the active lumbo-pelvic core subsystem considering the literature on injury causation in female athletes. The secondary objective was to also identify intrinsic and extrinsic factors of injury within this cohort of 15 female long-distance runners.

This chapter illustrates the results obtained from the questionnaire and both baseline and post-exercise data forms. The results are displayed to reflect the demographic information of this cohort followed by the lumbo-pelvic core profiles drawn from each of the testing procedures. Each profile demonstrates a characteristic of the active stability subsystem of the lumbo-pelvic core.

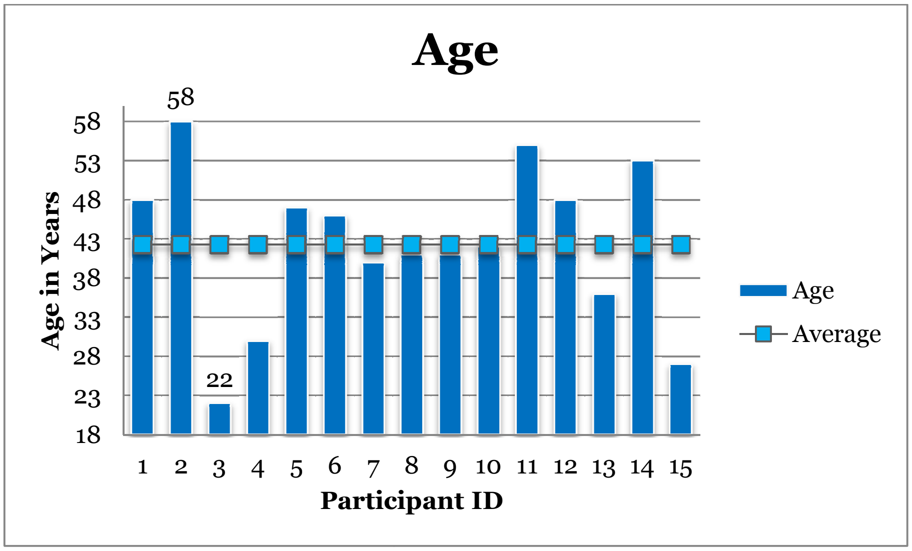
The chapter concludes with the internal and external factors of injury causation identified within this sample of female runners. The results are only narrated to highlight their significance within the represented profiles. Interpretation and discussion of the findings follows in Chapter 5.

4.1. DEMOGRAPHIC INFORMATION

The demographic information displayed in this section provides an overview of the cohort of female long-distance runners. A number of these variables have also been identified in literature to be contributors to injury. This will only be noted within this section and discussed within Chapter 5.

4.1.1. AGE

The average age of the 15 female long-distance runners was 43 years (Graph 1). The minimum cut-off age was 18 years. The youngest participant was age 22 and the eldest 58 years. Age is also considered an internal contributor to injury (2.6.1.2.)

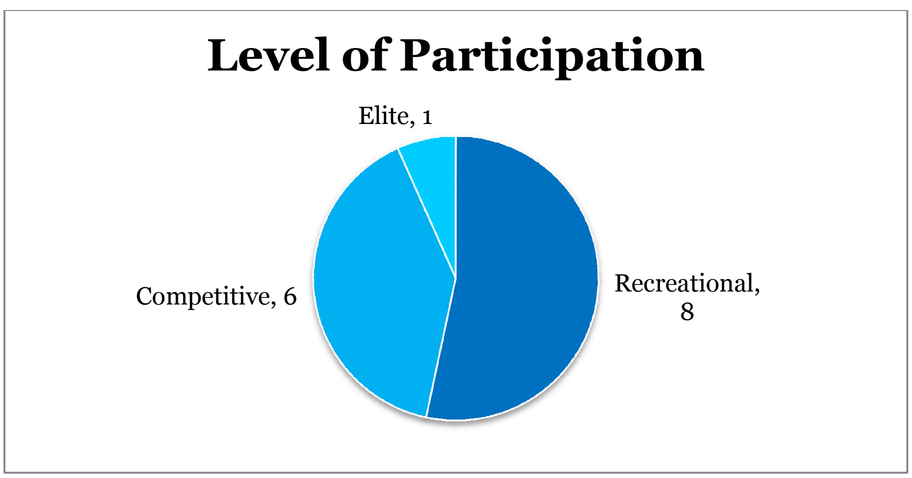


GRAPH 1: AGE

N=15

4.1.2. LEVEL OF PARTICIPATION

The majority (n=8) of the participants were recreational runners (Graph 2). This included partaking in marathon running for enjoyment. Six (6) runners were competitively involved in races and one (1) runner competed at international level. The cohort was therefore representative of all levels of participation.



GRAPH 2: LEVEL OF PARTICIPATION

N=15

4.1.3. Co-MORBIDITIES

No co-morbidities influencing skeletal muscle were identified (Figure 5).

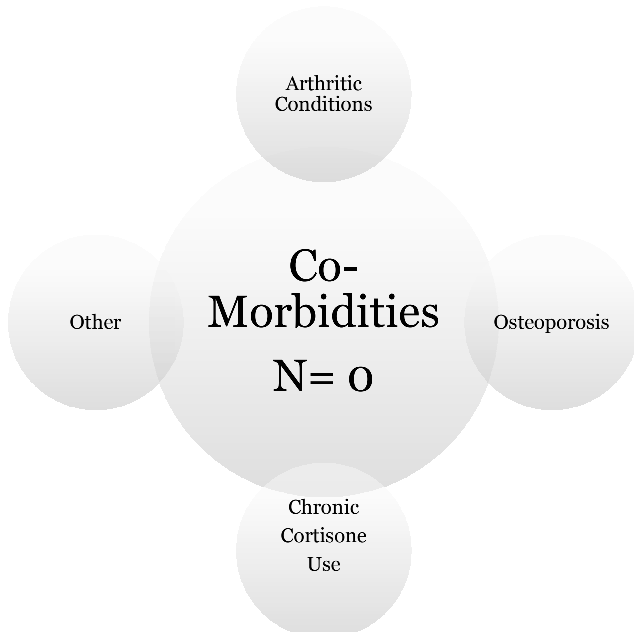
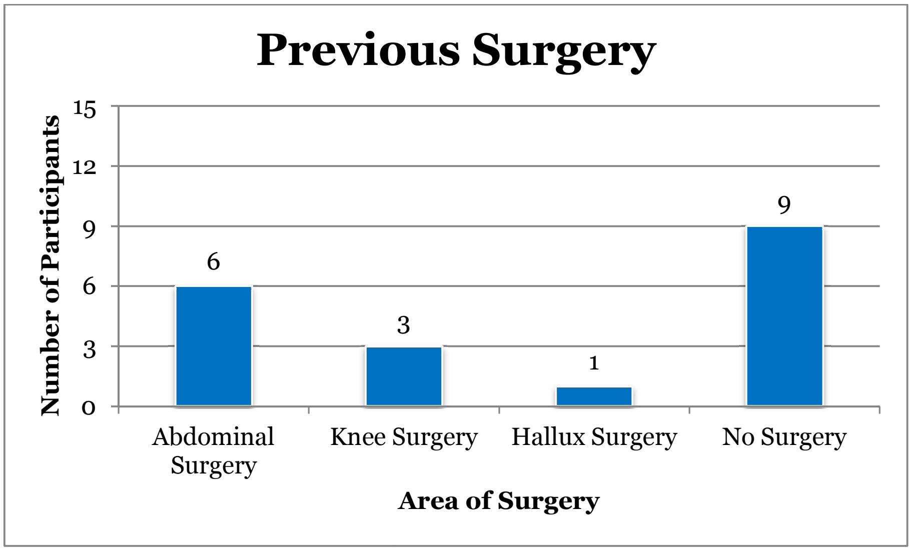


FIGURE 8: CO-MORBIDITIES

N=15

4.1.4. PREVIOUS SURGERY

Ten (10) participants had previous surgery within areas of the lower-limb kinetic chain (Graph 3). Six (6) respondents had previous abdominal surgery while three (3) participants have had knee surgery and one (1) underwent a bunion removal.

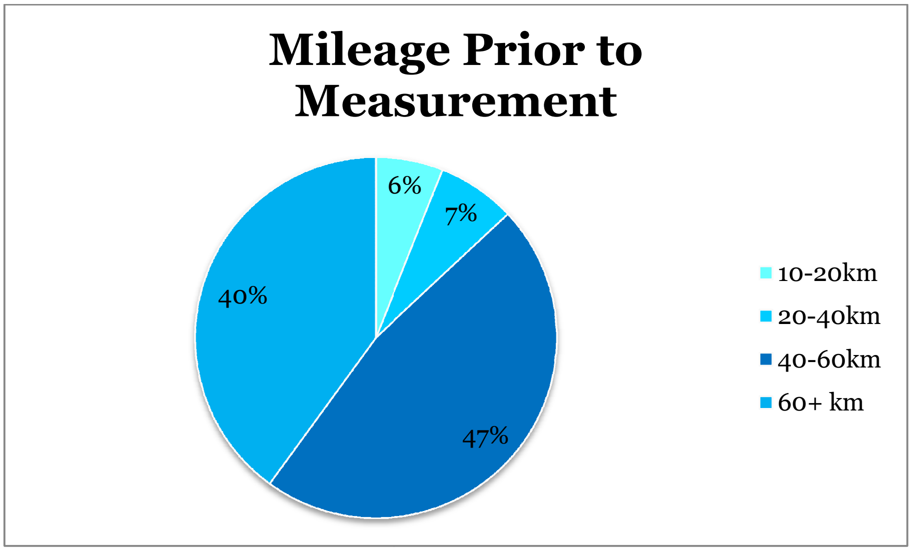


GRAPH 3: PREVIOUS SURGERY

N=15

4.1.5. MILEAGE PRIOR TO BASELINE MEASUREMENT

The majority of the female runners (47% and 40%) completed training distances of more than 60 and 40 weekly kilometers respectively the seven (7) days prior to participation in this study (Graph 4). The remaining thirteen percent (13%) still completed mileages higher than five (5) kilometers.

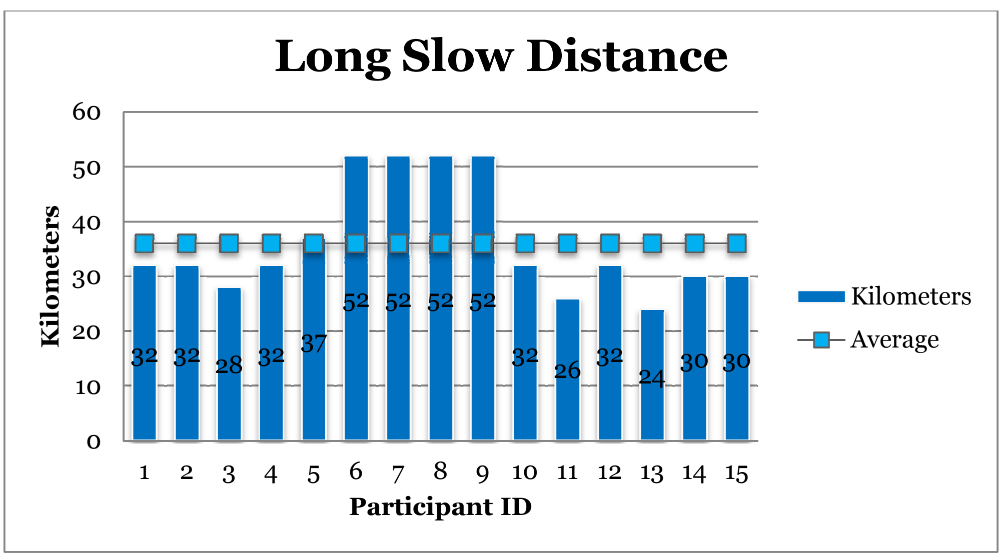


GRAPH 4: MILEAGE ONE WEEK PRIOR TO BASELINE MEASUREMENT

N=15

4.1.6. THE FUNCTIONAL ENDURANCE-EXERCISE TASK

The participants completed a functional long slow distance run as functional task to determine the effect on the lumbo-pelvic core system (Graph 5). An average of 36 kilometers was completed. The minimum cut-off value was 24 kilometers.



GRAPH 5: THE LONG SLOW DISTANCE FUNCTIONAL ENDURANCE-EXERCISE TASK

N=15

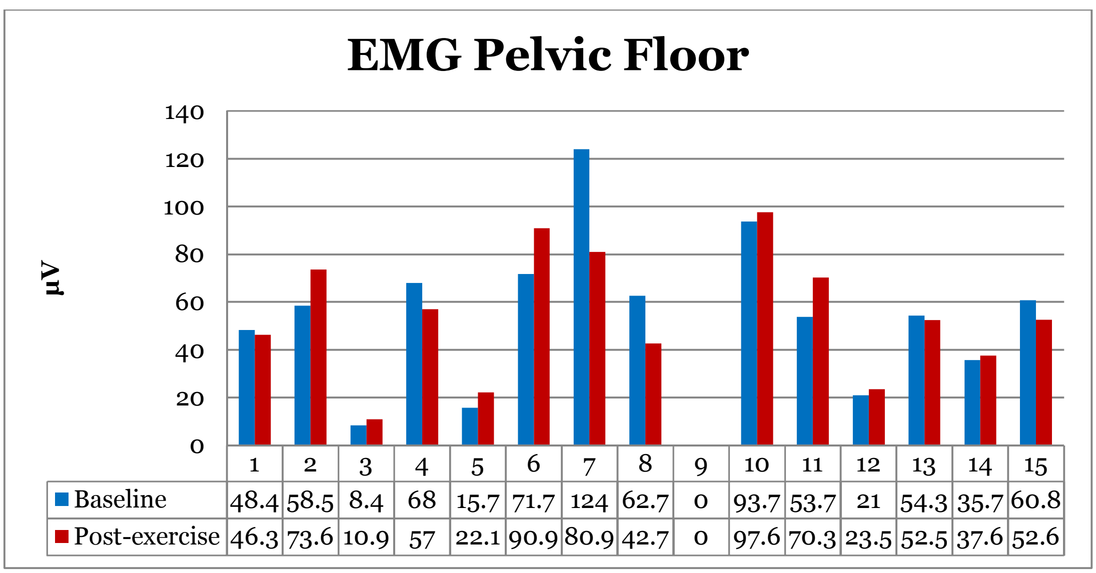
4.3. THE ACTIVE SUBSYSTEM OF THE LUMBO-PELVIC CORE

The profiles of each component of the active subsystem of the lumbo-pelvic core are displayed both at baseline measurement and after completion of the functional endurance-exercise task (Graph 5). In the next section (4.3.4.) the analysis for statistical significant differences ($p<0.05$) will be depicted.

4.3.1. ELECTROMYOGRAPHY (EMG) PROFILES

4.3.1.1. THE PELVIC FLOOR MUSCLES

The EMG-profiles of each participant's pelvic floor muscles are displayed both at baseline and after the LSD. The results in microvolts (µV) represent the maximum muscular contraction held for ten (10) seconds. The profiles of six (6) participants displayed an increase in post-exercise muscle recruitment. No statistical significant difference ($p=0.7957$) was found between the baseline and post-exercise values.

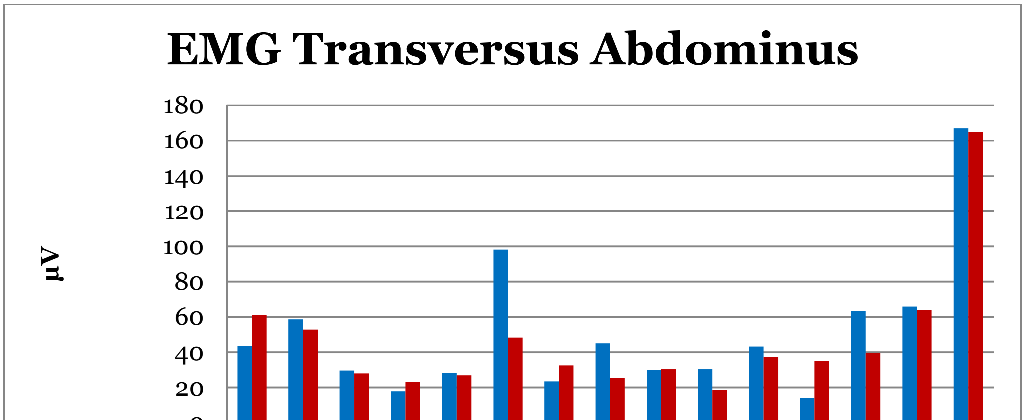


GRAPH 6: EMG MEASUREMENT OF THE PELVIC FLOOR MUSCLES

N= 14; 0 = missing

4.3.1.2. M. TRANSVERSUS ABDOMINUS

Graph 7 depicts each participant's TrA EMG-profiles. The results in microvolts (µV) reflect the activation of TrA for ten (10) seconds. The majority of the profiles (n=9) displayed a decrease in post-exercise muscle recruitment. There was no statistical difference (p=0.2769) established between the baseline and post-exercise profiles.



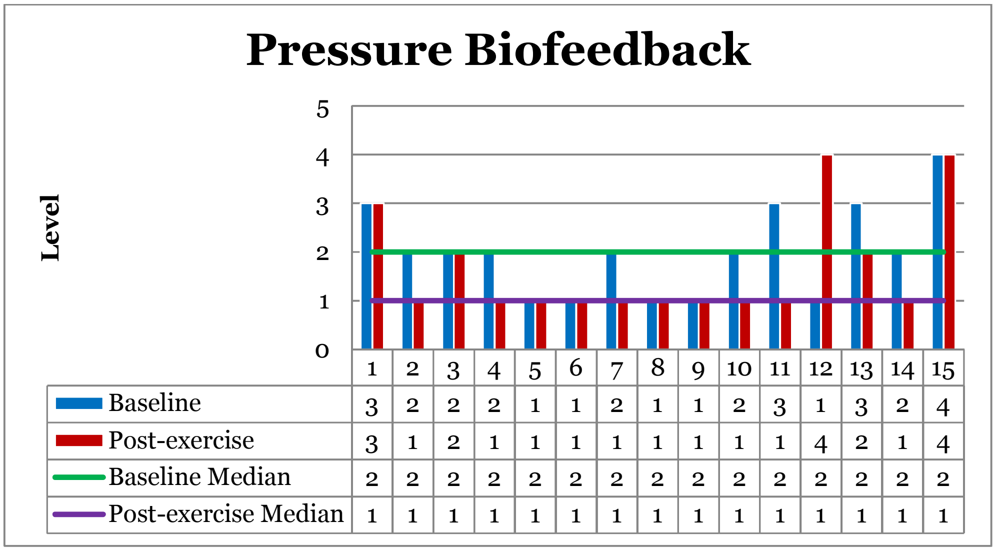
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Baseline	44	59	30	18	28	98	24	45	30	31	43	14	63	66	167
Post-exercise	61	53	28	23	27	48	33	25	30	19	38	35	40	64	165

GRAPH 7: EMG MEASUREMENT OF THE TRANSVERSUS ABDOMINUS MUSCLE

N = 15

4.3.2. PRESSURE BIOFEEDBACK PROFILES

The Pressure Biofeedback profile level (Addendum G) of each of the fifteen participants, both at baseline and after the LSD, is displayed in Graph 8. The median baseline level was level 2. Seven (7) profiles indicated a decrease in post-exercise level. However, four (4) profiles indicated both minimum baseline and a post-exercise level of 1, with level 5 as maximum value. A total of ten (10) post-exercise profiles were at minimum level (level 1), with the median level of the cohort post-exercise also level 1. The differences between the baseline and post-exercise profiles were not statistically significant (p=0.1875).



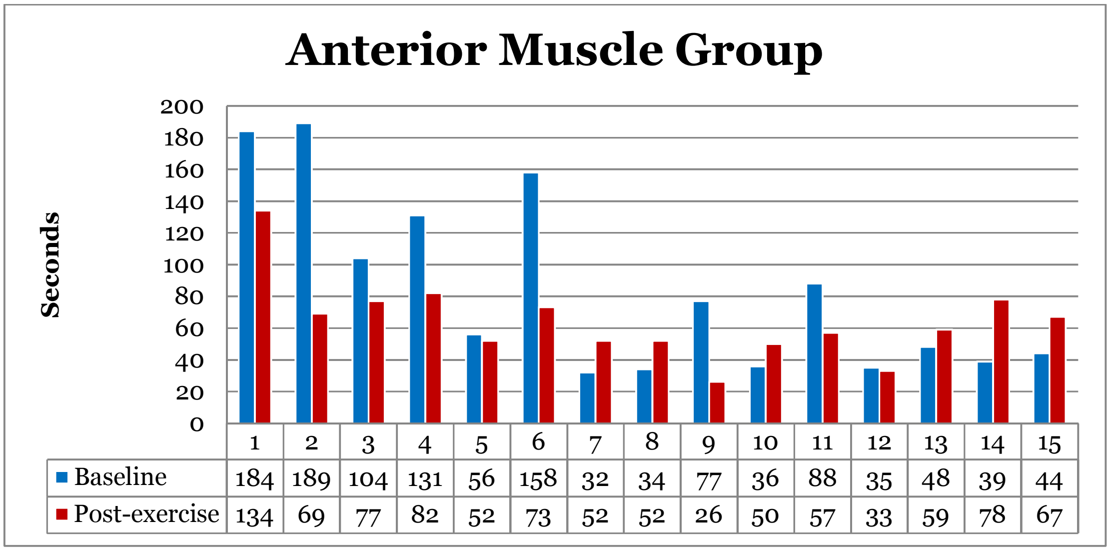
GRAPH 8: PRESSURE BIOFEEDBACK MEASUREMENT OF PROXIMAL STABILITY

N= 15

4.3.3. FUNCTIONAL ENDURANCE PROFILES

4.3.3.1. THE ANTERIOR MUSCLE GROUP

The endurance profiles of the anterior muscle group at baseline and after the LSD are displayed in seconds for the fifteen participants (Graph 9). Six (6) profiles indicated an increase in endurance post-exercise. No changes within the cohort were statistically significant (p=0.1688).

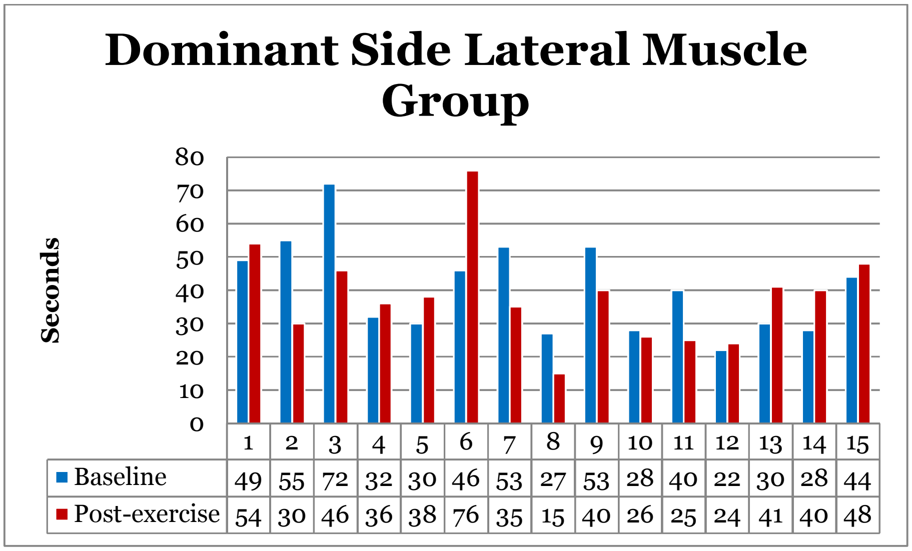


GRAPH 9: ANTERIOR MUSCLE GROUP

N= 15

4.3.3.2. THE LATERAL MUSCLE GROUP: DOMINANT SIDE

The lateral muscle profiles of the dominant side are represented in seconds in Graph 10. Eight (8) of the post-exercise profiles indicated an increase in post-exercise muscle endurance on the dominant lateral side. The changes within the profiles were not statistically significant (p=0.5897).

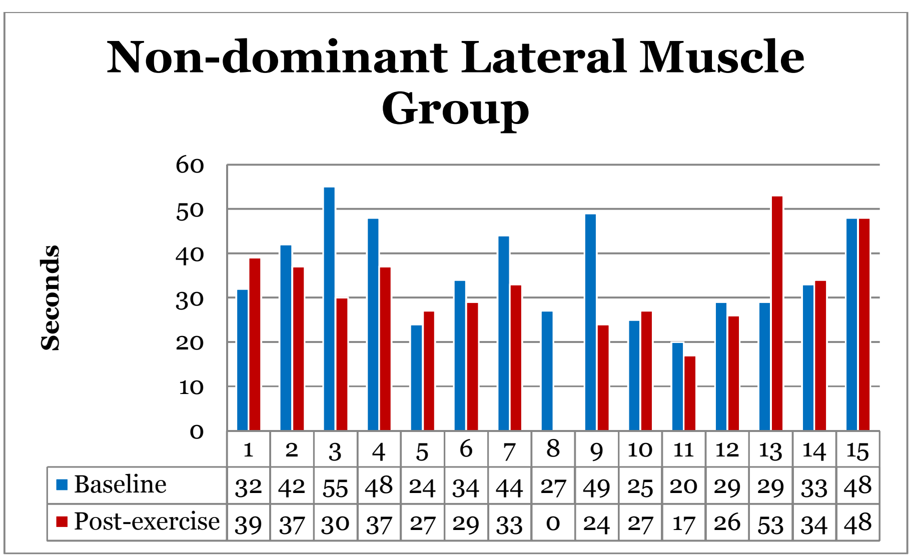


GRAPH 10: DOMINANT SIDE LATERAL MUSCLE GROUP

N=15

4.3.3.3. THE LATERAL MUSCLE GROUP: NON-DOMINANT SIDE

The results for each participant's non-dominant side lateral muscle group testing at baseline and after the LSD are displayed in seconds (Graph 11). Five (5) profiles were indicative of increased endurance of the non-dominant lateral muscles measured after the functional LSD. No statistical significant difference was established (p=0.1848).

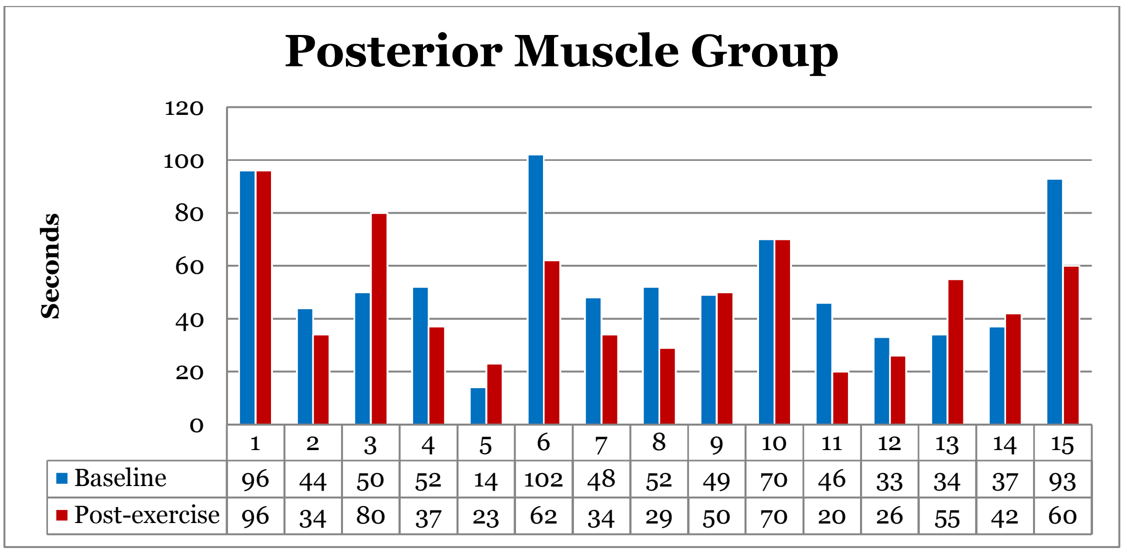


GRAPH 11: NON-DOMINANT SIDE LATERAL MUSCLE GROUP

N=15; 0 = missing

4.3.3.4. THE POSTERIOR MUSCLE GROUP

Graph 12 illustrates the baseline and post-exercise profiles for the posterior muscle group of each participant measured in seconds. Five (5) of the fifteen (15) profiles reflected an increase in posterior muscle endurance. No statistical significant change was established between the profiles (p=0.1909).



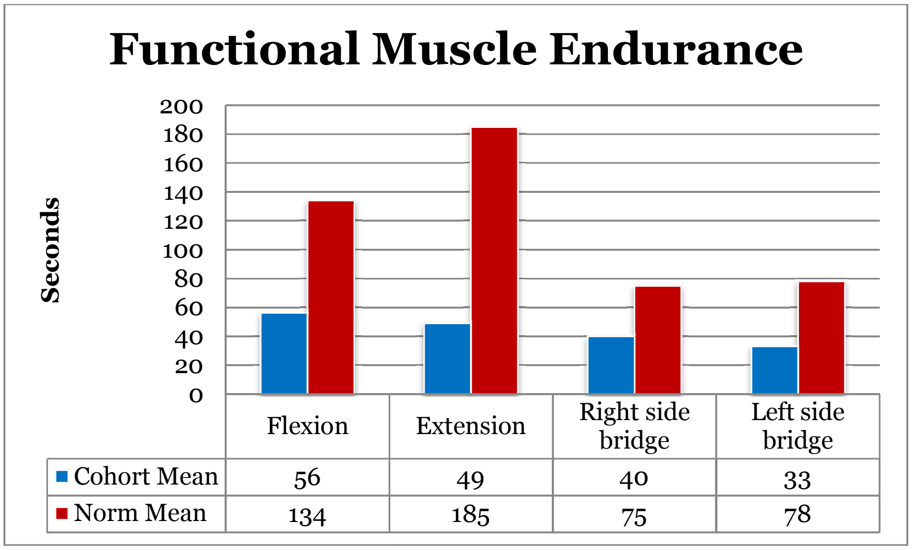
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Baseline	96	44	50	52	14	102	48	52	49	70	46	33	34	37	93
Post-exercise	96	34	80	37	23	62	34	29	50	70	20	26	55	42	60

GRAPH 12: THE POSTERIOR MUSCLE GROUP

N=15

4.3.3.4. COMPARISON OF FUNCTIONAL MUSCLE ENDURANCE WITH NORMATIVE VALUES

The difference between the averages in baseline functional endurance testing of the cohort and the norm are noteworthy since a sporting population completing an endurance distance above 24 kilometers should be comparable or even higher than a non-sporting population as was used to determine the normative values (Addendum I). The differences were especially marked within the sagittal plane. This is relevant as sagittal excursions of the lower limb increase during running (2.2.). Please note that no statistical comparison is made.



GRAPH 13: COMPARISON OF THE MEAN VALUES OF FUNCTIONAL ENDURANCE OF THE COHORT WITH NORMATIVE VALUES

4.3.4. ACTIVE SUBSYSTEM PROFILING

The profiles of the cohort at baseline and post-exercise are summarised to display the upper- and lower quartile and medians (Table 4). The difference between the baseline and post-exercise measurements were calculated at the mean value ± the standard deviation for each variable. There was no statistical significant difference ($p<0.05$) between the baseline and post-exercise values of any of the variables measured relating to the active subsystem of the core. This also emphasised the importance to analyse factors in the following section that could affect performance and therefore statistical differences between the measurements.

TABLE 4: SUMMARY OF AND DIFFERENCE BETWEEN THE BASELINE AND POST-EXERCISE PROFILES

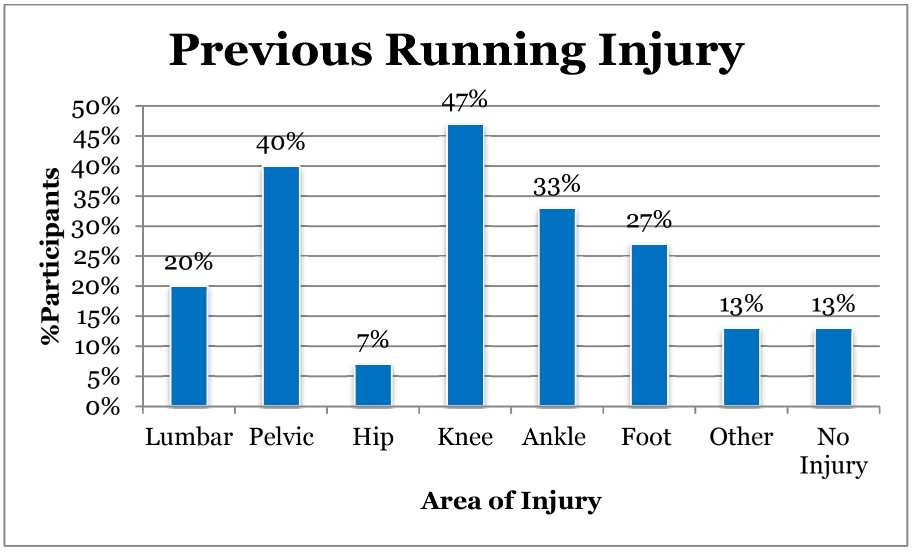
Variable	N	Baseline Measurement			Post-exercise Measurement			Difference (mean ±s)	P Value
		Upper Quartile	Median	Lower Quartile	Upper Quartile	Median	Lower Quartile		
PFM (µV)	14	68	56.4	35.7	73.6	52.6	37.6	1.29 ± 16.11	0.7957
TrA (µV)	15	63.3	43.3	28.4	52.9	35	27.00	4.68± 17.32	0.2769
PBU (Level)	15	3	2	1	2	1	1	0.33 ± 1.11	0.1875
Anterior Muscles (seconds)	15	131	56	36	77	59	36	19.6 ± 44.85	0.1688
Dominant Lateral Muscles (seconds)	15	53	40	28	46	38	26	2.33 ± 15.53	0.5897
Lateral Muscles (seconds)	15	48	33	27	37	31.5 (N=14)	27	3.642 ± 12.44	0.1848
Posterior Muscles (seconds)	15	70	49	37	62	42	29	6.8 ± 19.31	0.1909

4.4. INTERNAL RISK FACTORS OF INJURY

4.4.1. GENERAL RISKS OF INJURY

4.4.1.1. PREVIOUS RUNNING INJURY

The predominant area of injury within the lower-limb kinetic chain is the knee with 47% of participants having reported a knee injury (Graph 14). Any previous injury of the lower-limb kinetic chain that prohibited seven (7) days of usual running training was reported for the purpose of this research. Proximal to the knee, pelvic and lumbar injuries were reported by 40% and 20% participants respectively. Thirty-three percent (33%) of participants had previous ankle injuries whereas 27% of participants previously suffered injuries in the foot. Two participants (13%) reported no running injury, with the definition of running injury referring to ailments that prevent seven (7) days of usual running.



GRAPH 14: PREVIOUS RUNNING INJURY

N=15

4.4.1.2. REHABILITATION OF PREVIOUS INJURY

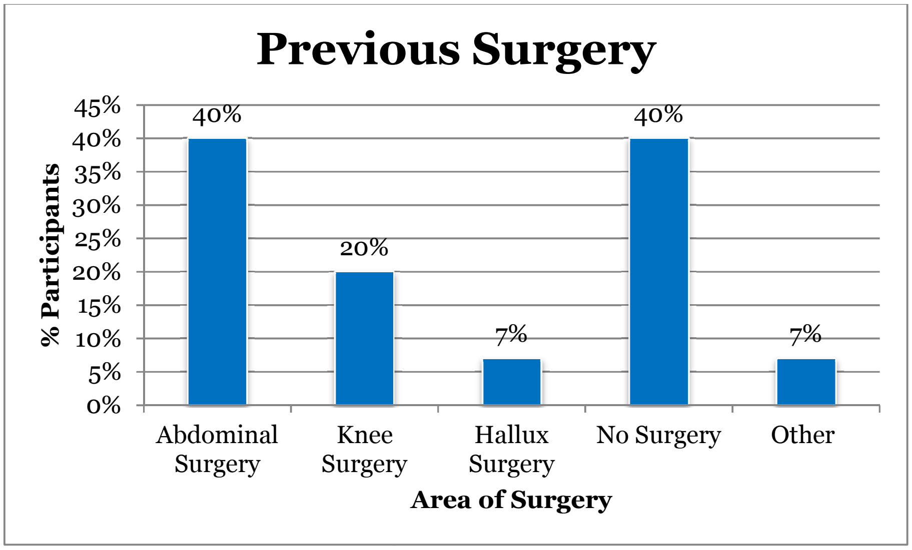
Only 31% of participants included the entire kinetic chain in injury rehabilitation with the majority (77%) of participants having reported rehabilitation under medical management (Table 4). Only one participant made use of a prosthetic brace for a drop-foot while running.

TABLE 5: REHABILITATION OF PREVIOUS RUNNING INJURIES

Management/Interventions	*Percentage Participants*
General exercises for the area of injury	23%
Specific exercises for the area injury along with core musculature (abdominal, back, leg muscles)	31%
Medical management (doctor, physiotherapist,biokineticist)	77%
Commenced with usual running regimen when pain/injury allowed	62%
Rest	54%
Other: Prosthetic bracing	8% (n=1)

N=13

4.4.1.3. PREVIOUS SURGERY



GRAPH 15: PREVIOUS SURGERY

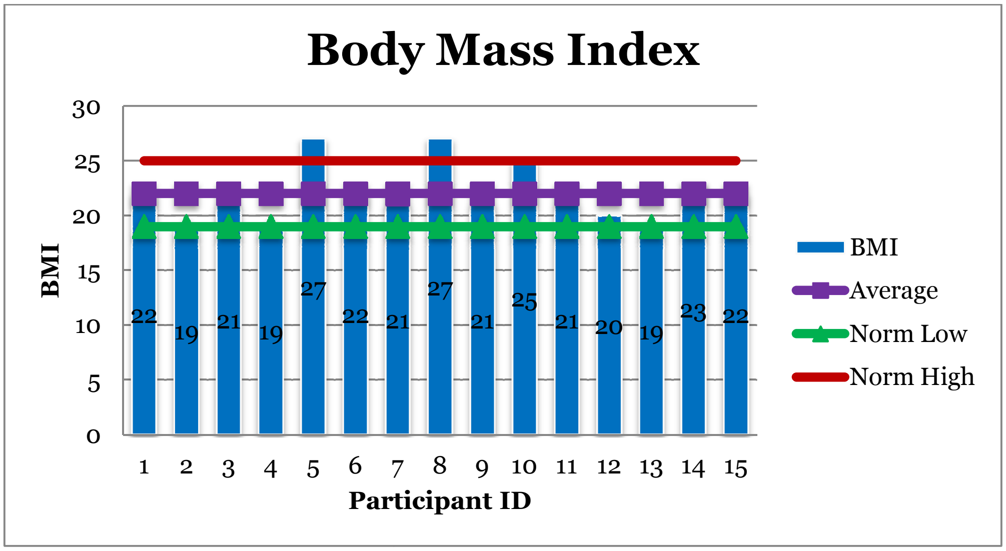
N=15

Surgery in the abdominal area was predominant followed by the knee with 40 % of participants having undergone abdominal surgery and 20 % of participants with previous knee surgery (Graph 15).

4.4.2. RISK OF STRESS URINARY INCONTINENCE

4.4.2.1. BODY MASS INDEX

The average BMI for the cohort was 22 kg/m^2 (Graph 16). Only two (2) participants had a BMI (27 and 27 kg/m^2) above the maximum normative level that could be indicative of increased risk of injury and SUI. Two (2) participants had a BMI at a minimum normative value of 19 kg/m^2.

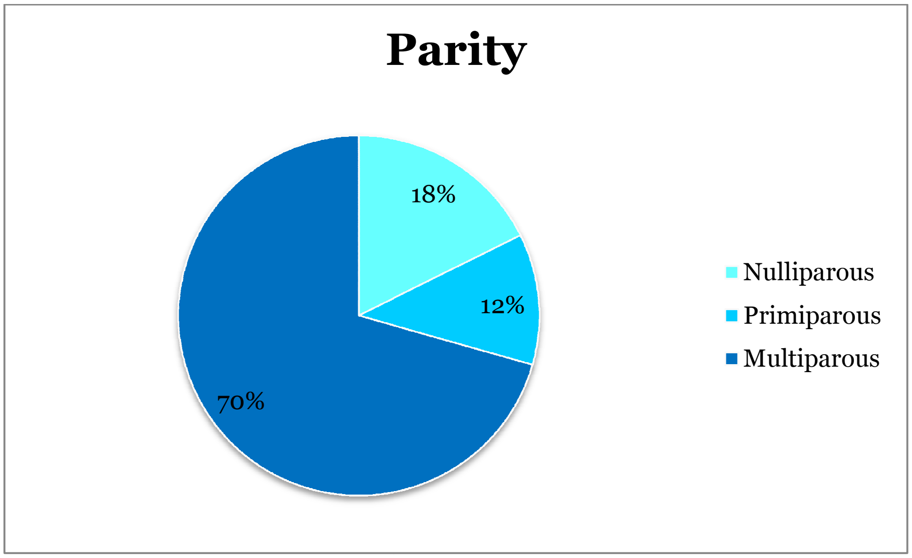


GRAPH 16: BODY MASS INDEX

N=15

4.4.2.2. PARITY

Eighty-two percent (82%) of the participants was classified as parous with the majority (70%) of the parous participants having presented with multiparity (Graph 17).

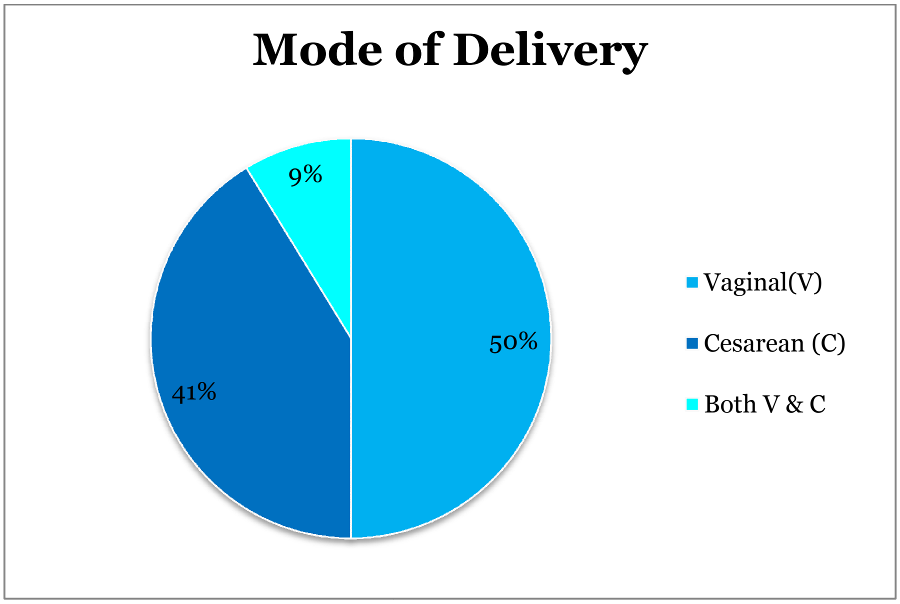


GRAPH 17: PARITY

N=15

4.4.2.3. MODE OF DELIVERY

Forty-one percent (41%) of the 12 parous participants reported exclusively delivering via caesarean section that prevents injury to the pelvic floor muscles (Graph 18). Forty-nine percent (49%) of parous participants reported a vaginal delivery which could indicate increased risk of SUI due to possible damage to the pelvic floor muscles (2.6.1.1.).



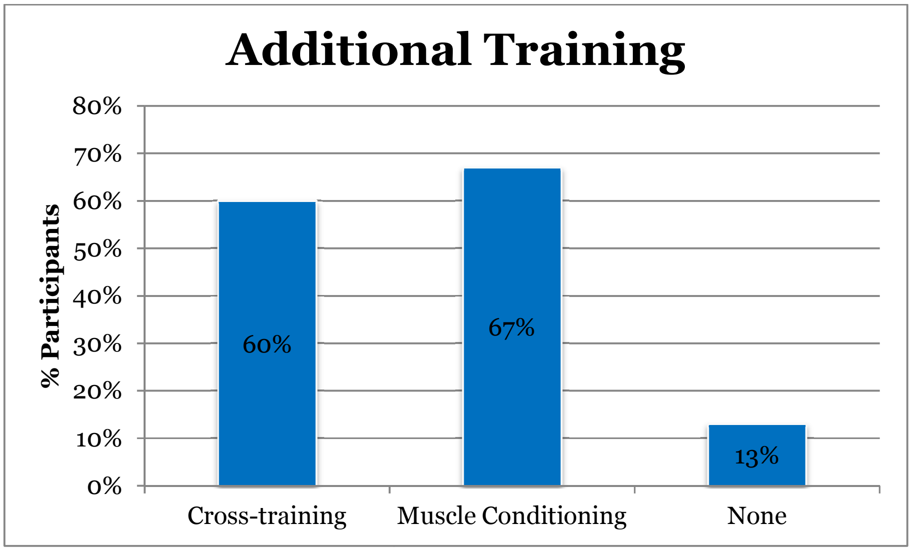
GRAPH 18: MODE OF DELIVERY

N=12

4.5. EXTERNAL RISK FACTORS OF INJURY

4.5.1. ADDITIONAL TRAINING

The majority of participants (67%) reported muscle-conditioning, including pelvic floor muscle exercises, as part of their training programs in adjunct to running (Graph 19). Sixty percent (60%) cross-trained e.g. cycled or swam. Thirteen percent (13%) of the participants reported running as the only exercise/conditioning modality.



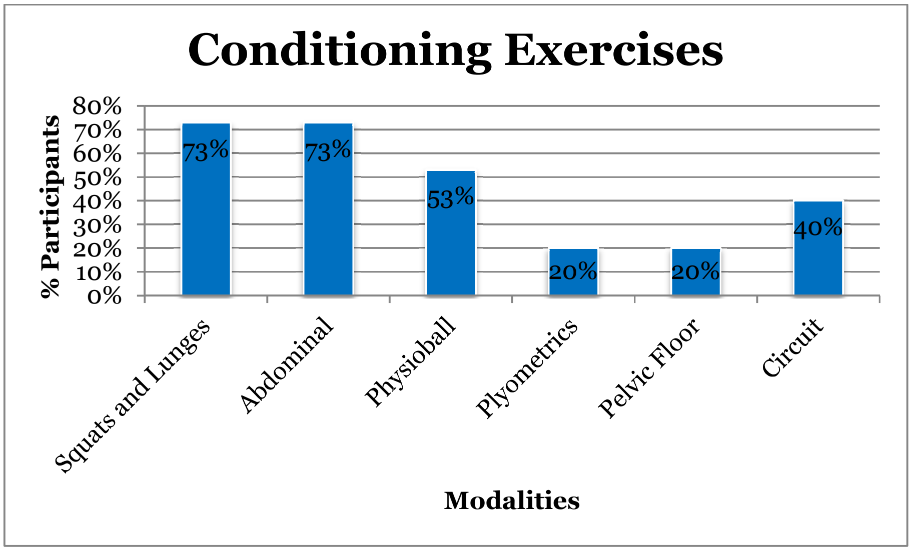
GRAPH 19: ADDITIONAL TRAINING

N=15

4.5.2. MUSCLE CONDITIONING

4.5.2.1. CONDITIONING MODALITIES

Seventy-three percent (73%) of the participants (n=13) that reported muscle-conditioning included squats and lunges and non-specific abdominal exercises in their exercise programs (Graph 20). Physioball exercises was also used by 53% of the participants (n=13). Only three (3) participants (20%) reported pelvic floor conditioning.



GRAPH 20: CONDITIONING EXERCISE MODALITIES

N=13

4.5.2.2. SPECIFICITY OF MUSCLE CONDITIONING

Ten (10) of the thirteen (n=13) participants reported endurance-based exercises with low weights at higher repetitions whereas the remaining three (3) also engaged in strength training with higher loads and less repetitions (Figure 9).

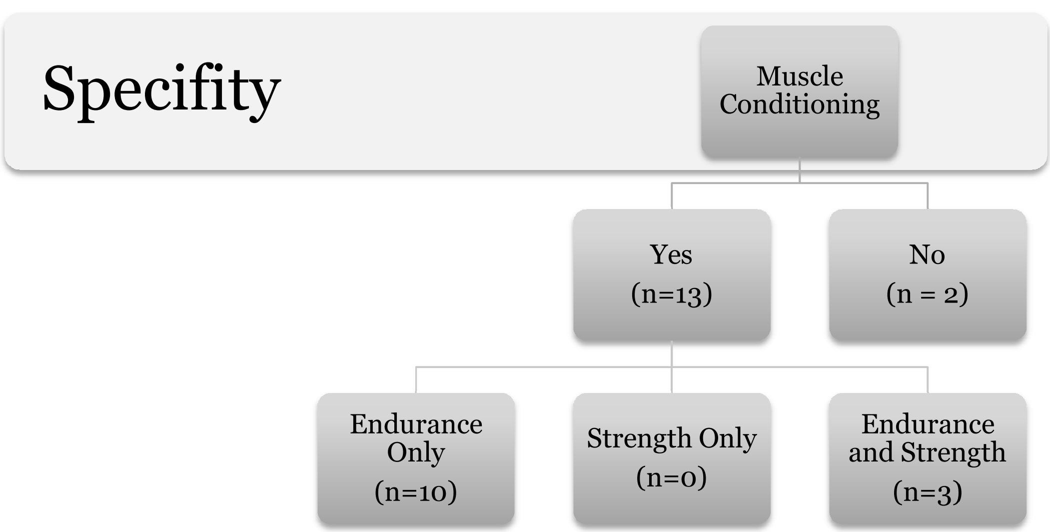
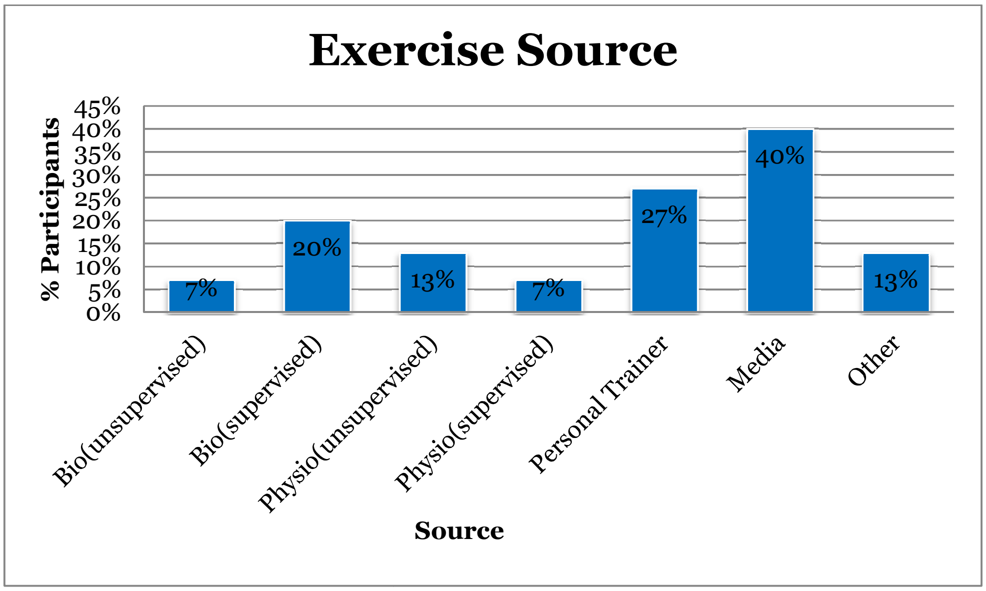


FIGURE 9: EXERCISE SPECIFICITY

4.5.2.3. SOURCE OF CONDITIONING EXERCISES

The media was the main source of exercise information with 40% of participants having identified the internet, running magazines and other sources as exercise source (Graph 21). Thirteen percent (13%) of the participants had exercise prescription from a physiotherapist and 7% from a biokineticist. Only 27% of participants engaged in supervised conditioning by a biokineticist (20%) or physiotherapist (7%).



GRAPH 21: SOURCE OF CONDITIONING EXERCISES

N=15

4.5.3. RUNNING-SPECIFIC TRAINING

4.5.3.1. WEEKLY MILEAGE INCREASE

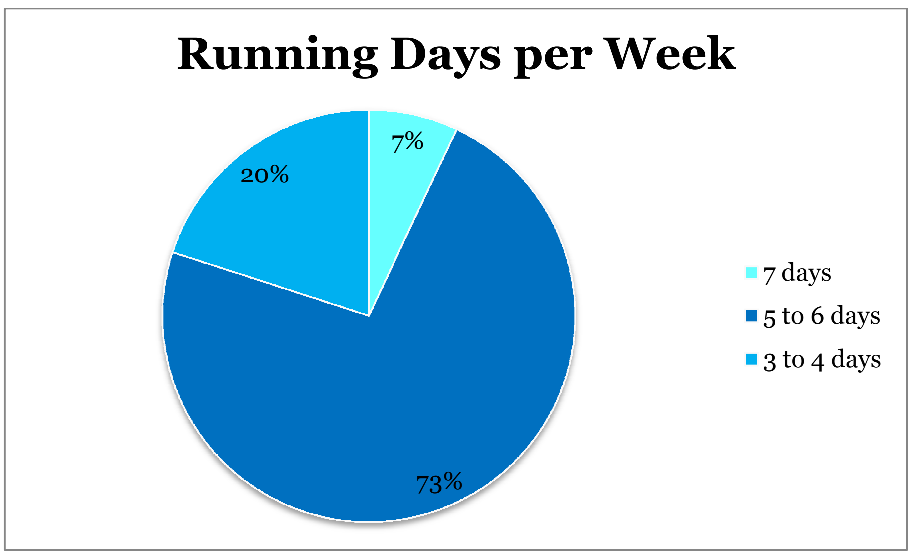
A noteworthy 53% of participants reported a sharp weekly increase in training mileage where running training-distances increase in high increments every day. Only 27% gradually increased weekly mileage by more or less ten percent (10%).

TABLE 6: WEEKLY TRAINING MILEAGE INCREASE

Mileage Increase	*Percentage Participants (n=15)*
Running one additional day per week	20%
Running more than one additional day per week	7%
Gradual increase of ± 10% weekly	27%
Running an extra session a day	0%
Sharp increase of mileage	53%

4.5.3.2. IN-SEASON WEEKLY RUNNING DAYS

Seventy-three percent (73%) of participants ran five to six days of the week within the running season. Only one participant (7%) reported running everyday within the running season (Graph 22).

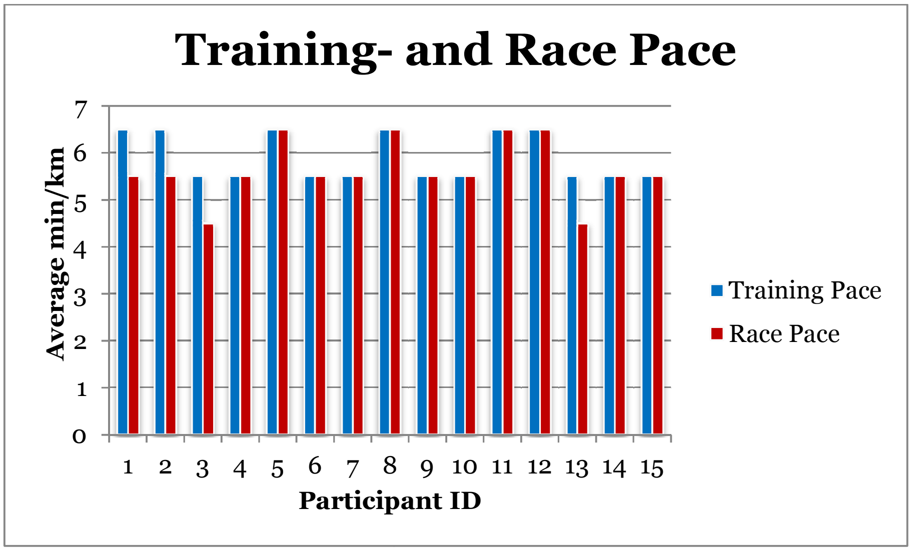


GRAPH 22: IN-SEASON WEEKLY RUNNING DAYS

N=15

4.5.3.3. TRAINING PACE VS. RACE PACE

Only four (4) participants trained at an average pace that are slower than their average race pace (Graph 23).

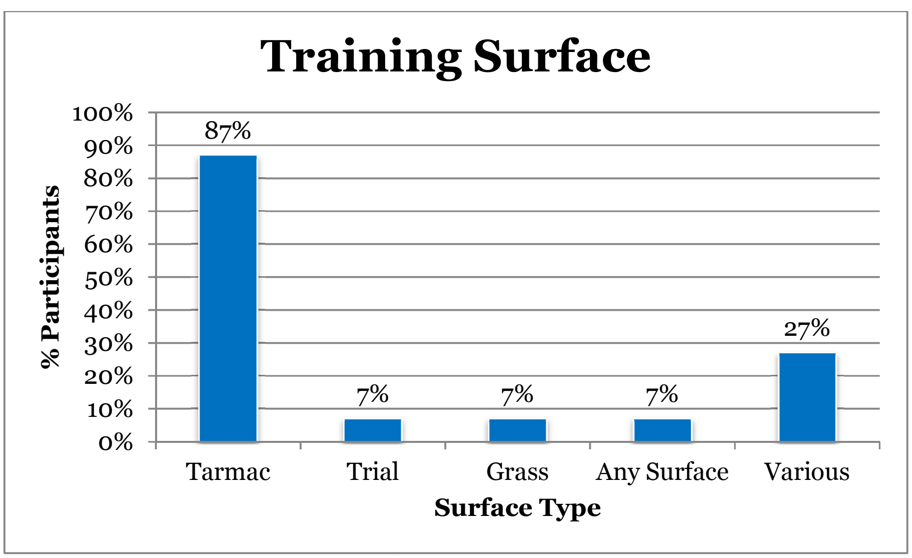


GRAPH 23: TRAINING PACE VERSUS RACE PACE

N=15

4.5.3.4. TRAINING SURFACE

A vast majority (87%) of participants trained on tarmac (Graph 24). This was anticipated within the definition of a long-distance runner in the context of this research. A combined 48% of participants also ran on surfaces other than tarmac during training.



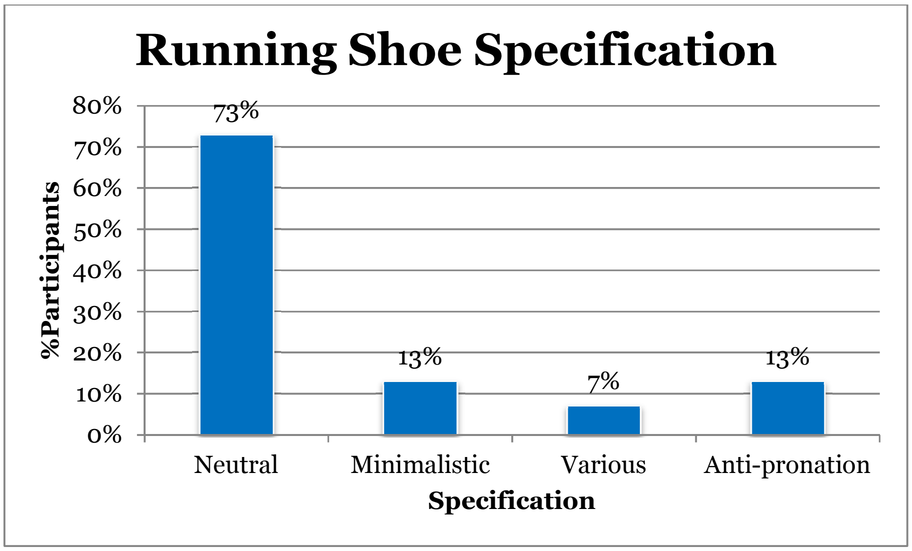
GRAPH 24: RUNNING TRAINING SURFACE

N=15

4.5.4. EQUIPMENT

4.5.4.1. RUNNING SHOE SPECIFICATION

A neutral running shoe was the choice of 73% of the participants (Graph 25). Thirteen percent (13%) of the participants (2 participants) ran with minimalistic shoes and one participant (7%) used a variety of running shoes.

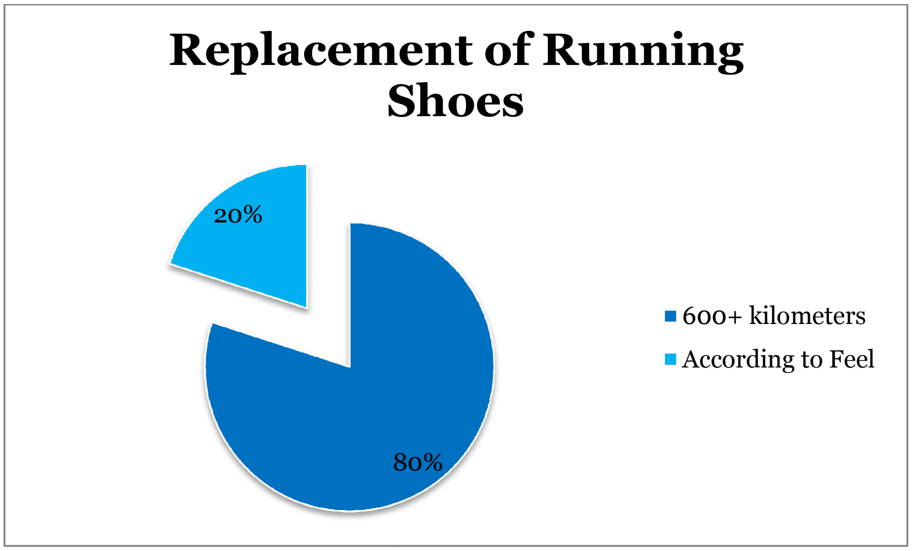


GRAPH 25: RUNNING SHOE SPECIFICATION

N=15

4.5.4.2. REPLACEMENT OF RUNNING SHOES

Twenty percent (20%) of participants replaced their running shoes with a new shoe according to their own judgement during running (Graph 26). The remaining 80% reported replacing their running shoe at six hundred or more (600 +) kilometres.



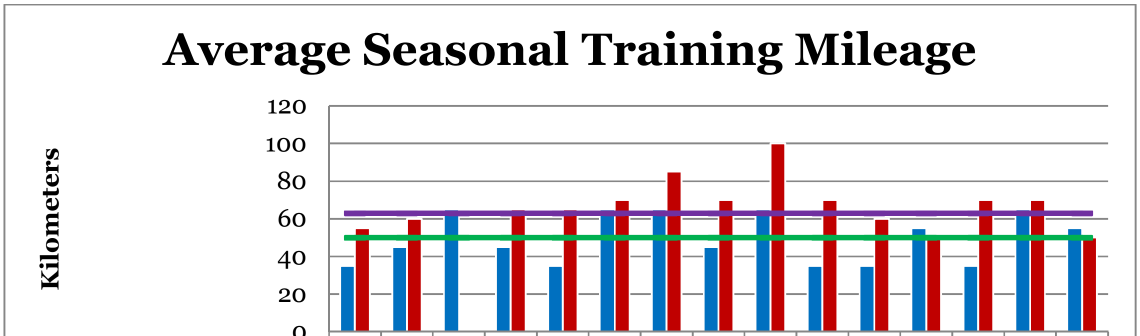
GRAPH 26: REPLACEMENT OF RUNNING SHOES

N=15

4.5.5. PERIODISATION

4.5.5.1. AVERAGE SEASONAL TRAINING MILEAGE

The majority of participants (n=13) reported a decrease in average training mileage in the off-season (Graph 27), while two (2) participants had a slight increase in average running mileage. The average of the off-season mileage for the cohort was thirteen (13) kilometres less per week when compared to during the running season.



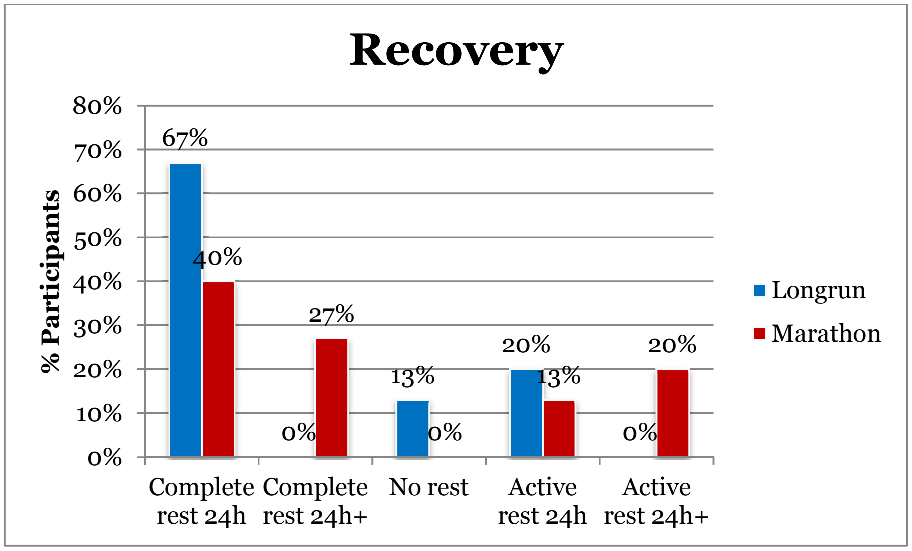
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Off-Season Km	35	45	65	45	35	65	65	45	65	35	35	55	35	65	55
In-season Km	55	60	0	65	65	70	85	70	100	70	60	50	70	70	50
Average Off-season	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Average In-Season	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63

GRAPH 27: AVERAGE SEASONAL TRAINING MILEAGE

N=15; 0=missing

4.5.6. RECOVERY

All the participants reported recovering after a marathon, with two (2) participants (13%) having stipulated no recovery following longrun training (Graph 28). Recovery from longrun(LSD) training was mainly by means of twenty-four (24) hours of complete rest (67% of participants) whereas recovery after marathons was by resting completely for twenty-four (24) hours (40% of participants). Twenty-seven percent (27%) of the participants engaged in complete rest for multiple days to recover from a marathon. Twenty percent (20%) of participants preferred active rest such as cycling and/or swimming for only one day (24 hours) to recover from a longrun whereas 20% of participants recovered from a marathon by actively resting for multiple days.



GRAPH 28: RECOVERY AFTER LONGRUNS AND MARATHONS

N=15; 0%=missing

4.6. CONCLUSION

The results displayed in this chapter illustrated several factors relating to injury within a cohort of female long-distance runners. Unexpected increases in the majority of post-exercise profiles were noted within the EMG, PBU and all the musclegroups. The high prevalence of previous injury that was not sufficiently rehabilitated was remarkable amongst other internal factors of injury causation identified within the cohort. Running training-related errors were identified as a possible external contributor to injury alongside insufficient recovery from LSD training. The changes within the profiles at baseline and post-exercise will be discussed in Chapter 5 as it pertain to injury causation alongside the identified internal and external factors of injury.

CHAPTER 5

DISCUSSION

This chapter interprets and discusses the results as they relate to the aims and objectives of this research. The research aims for this study were to utilise baseline and post-exercise profiling of the active subsystem of the lumbo-pelvic core to identify and discuss the differences after a functional exercise as it may relate to movement dysfunction and therefore injury. The profiles compiled (4.4) included EMG profiles characterising the muscle recruitment of the PFM and TrA, the pressure biofeedback level of integrated proximal stability and functional endurance testing of the anterior, posterior and lateral muscle groups of the core. A secondary objective of this study was to describe internal and external factors of running-injury causation, including SUI, within a population proven to be struck by a high prevalence of especially lower-limb injury.

5.1. THE COHORT OF FEMALE LONG-DISTANCE RUNNERS: AN OVERVIEW

The sample included fifteen (15) experienced female long-distance runners (average age 43 years) with the majority of the runners competitive and recreational runners. The ages of the participants (Chapter 4, Graph 1) are comparable to good-quality reviews on risk factors for running injury causation (Nielsen *et al.*, 2012:58). The limitation in sample size is consistent with previous research that includes pelvic floor testing of female participants (Luginbuehl, Naeff, Zahnd, Baeyens, Kuhn, & Radlinger, 2016:118; Sapsford, 2008:1742). Similar to this report, sample sizes in research on core stability in runners are also influenced by the distances that runners complete (Schache *et al.*,2003:106). The differentation between experienced and novice runners are higlighted, but not within the levels of participation in both research on core stability and running-injury causation (Nielsen *et al.,* 2012:70). With only one (1) elite runner that partook in the study, no inferences on additional contributions/factors pertaining to elite athletes are made in the discussion of the core profiles (4.1.).

5.2. THE LUMBO-PELVIC CORE PROFILES

Participants underwent baseline profiling on days of complete rest from running and/or exercise. The majority (87%; n=13) of the runners completed training mileages higher than forty kilometers (40-60+ km) the week (7 days) prior to measurement (Chapter 4, Graph 4).

With profiling taking place within the running season, these mileages were not expected to negatively influence the baseline values of the profiles as the majority of participants trained within a predominant anaerobic oxidative system not only the week before, measurement, but also earlier in the running season (2.5.2.2.). It was therefore assumed that all participants were subjected to similar components of fatigue secondary to endurance activities.

Post-exercise profiling was in keeping with this same rational of anaerobic oxidative training with only LSDs greater than twenty-four kilometres (24 km), averaging thirty-six (36) kilometres, that was completed as functional endurance/exercise task for this study (Chapter 4, Graph 5). This distance is often used as LSD in training and running for two hours (24 km in LSD training is equal to more or less two hours of running) has been shown to result in isometric strength loss in lower-limb muscles (Millet & Lepers, 2004:106). No co-morbidities that may influence skeletal muscle physiology existed within this group (Chapter 4, Figure 8).

5.2.1. THE EMG PROFILES

In contrast to the hypothesised decrease in muscle recruitment after a prolonged endurance activity, six of the PFM profiles and the majority (n=9) of the TrA profiles showed an increase in muscle recruitment (Chapter 4, Graph 6 and 7). This increase in EMG activity might still be representative of a reduction in stability as the redistribution of muscle activity attempted to augment stability. The redistribution either altered the direction of force or redistributed the load between the structures. Therefore both the increased (secondary to increased redistribution) and decreased (secondary to decreased redistribution/structure failure) EMG values in the post-exercise profiles may be indicative of fatigue and/or overuse (Jull *et al.*, 2015:57).

Caution should however be taken to infer the presence of fatigue within simplified EMG measurement such as was used for the purpose of this research. Muscle fibre conduction velocity, power spectral frequency analysis and signal amplitude estimates must be determined to conclude true fatigue within EMG values (Jull *et al.*, 2015:170).

No statistical significant difference was established between baseline and post-exercise EMG profiles for both the PFM (P=0.7957) and the TrA (P=0.2769)(Chapter 4, Table3). The clinical significance however lies with the plausible redistribution to proximal areas or the replacement of tonic bursts with more phasic activity as gathered from the global-biased functional endurance profiles discussed in section 5.2.4.

Reduction in γ-motor neuron excitability brings about diminished proprioception and segmental control (2.1.1.2.). Should the EMG values of these predominant local stability profiles indeed have been indicative of an attempt to restore this loss of motor control, these runners may indeed be predisposed to degenerative or overuse changes within the movement system (Chapter 2, Figure 3). True markers of fatigue within the EMG were however not within the scope of this research.

5.2.2. PRESSURE BIOFEEDBACK PROFILES

The plausibility of the EMG profiles being indicative of re-distribution to compensate for stability loss within this cohort, are supported by the pressure biofeedback profiles. Even though only seven (7) profiles reflected a non-statistically significant (P=0.1875) decrease in post-exercise level, ten (10) of the fifteen (15) participants had a minimum post-exercise level 1, with the median post-exercise level of the cohort being level 1. The baseline median equaled a level 2 (Chapter 4, Graph 8). The implication thereof lies within the low-level ability of the active proximal stability system to function optimally during a non-challenging, anti-gravity lower limb load without exposure to fatigue. An even lessened ability to maintain proximal stability lower limb load loading was determined after a distance run that has been proven by previous research to induce central fatigue (2.4.2.).

The central nervous system is responsible for activating the protective feed-forward anticipation of this low-load limb movement. It might be reasoned that the redistribution within the EMG profiles of the TrA and PFM was indicative of the inability of the central nervous system to relay this afferent input from the muscle spindles of the active core system (Comerford & Mottram, 2001:16-17).

The loss in biomechanical stiffening then necessitates a redistribution of force and load that measured both as increase and decrease in muscle recruitment on the EMG aswell as a decrease in the level of proximal control during pressure biofeedback testing. Therefore, the inference can be made that if fatigue was induced within the core musculature by the functional endurance tasks/LSD, it resembles more central fatigue mechanisms previously identified in more distal structures (2.4.2). No scientific measures to accurately establish central fatigue was used for this research.

The pressure biofeedback testing was the closest to mimicking the functional task participants were exposed to in this research. Still, the biomechanics of running exposes the proximal stability system to much greater, repetitive and gravitational loads. The low baseline median proximal stability level of this *healthy, uninjured* cohort (level 2 of 5) is therefore concerning as it can be assumed that these runners trained and competed in extreme endurance activities without sufficient ability of the central nervous system to recruit the feed-forward stability muscles. The resulting proprioceptive deficit and movement dysfunction could therefore increase their risk of overuse and recurrence of injury (Chapter 2, Figure 3).

Several participants conveyed the increase in concentration they needed during pressure biofeedback testing post-exercise. This increase in sense of effort may also have suggested a more central induced fatigue as the increased sense of effort also occurs on a central nervous system level and is increased by muscle fatigue due to reflex inhibition of the motor neuron pool (2.1.1.2.). No studies reviewed for this research mention any subjective feedback from participants. This may be contributed to the majority of the research focusing on isolated muscle/ muscle groups and again reiterates the lack of research on the integrated core system.

5.2.3. STRESS URINARY INCONTINENCE

The EMG and PBU profiles of the three (3) participants reporting SUI could be interpreted as neuromuscular mechanisms (see 5.2.1.) in attempt to augment continence. The participant that experienced SUI during running had the highest PFM recruitment during baseline profiling, but the post-exercise profile revealed the greatest decrease in value (Profile 7, Graph 6). This runner's TrA profiles however revealed activity below the lower quartile in baseline measurement with an increase in post-exercise measurement, but also below the median for the cohort (Chapter 4, Graph 7, Profile 7; Chapter 4, Table 3).

Controversy still exists as to the co-contraction of the PFM and TrA. Even though no formal correlation was established for this research, it can be interpreted that the decreased ability to recruit the TrA (24 μV) and maintain stability during baseline measurement was displayed in the redistribution of load to the co-contracting PFM resulting in the high value (124 μV) recorded. Likewise, even though not statistically significant, the noticeable decrease in PFM in the post-exercise profile (80.9 μV) was accompanied by a slight increase in TrA (33μV) recruitment (Chapter 4, Graph 7, and Profile 7). This again might have indicated the increase in recruitment of co-contracting musculature as a method of compensation/redistribution (see 5.2.1.).

The same tendency was present in the profiles of the runner who reported SUI during plyometric exercises (Chapter 4, Graphs 6 & 7, profile 4). The profiles of the runner who reported SUI during ADL activities displayed a similar pattern, but with lower quartile measurements for both baseline and post-exercise PFM profiles. These lower quartile values of the PFM profiles were accompanied by TrA profiles with median- to upper quartile values. This possibly indicated recruitment of the TrA to co-contract in attempt to augment stability and continence (Chapter 4, Graphs 6 & 7, Profile 14; Chapter 4, Table 3).

The descriptions of the SUI related profiles are in agreement on research that correlated SUI with altered PFM characteristics (2.3.). This research also indicates a tendency of co-contraction activity within the PFM and TrA to augment tonic stability loss within the other both at rest and in response to a functional endurance activity. This conclusion is comparable to Sapsford's (2004:6) that an independent

TrA contraction can guarantee the required low-level pelvic floor activation needed for movement (2.3.).

In addition, the PBU profiles of the three (3) participants also displayed a decrease from level 2 to level 1 and thus the very limited ability of the active core subsystem to control movement both at rest and after exercise. The SUI within this cohort might therefore be explained by the PFM having to enhance stability and control to such an extent that it fails to also maintain continence (see 2.3.). This substantiates the recommendation from authors to include the local and global core in rehabilitation of SUI (Sapsford, 2007).

Irrespective of the co-contracting characteristics of the PFM and TrA, the static anti-gravity nature of the EMG measurements may not be indicative of the muscle recruitment characteristics during running. The importance of functional testing lies in the phasic recruitment by the predominant tonic PFM group during prolonged running. This was demonstrated by Luginbeheul *et al.* (2016:8) that showed increased resting PFM EMG values during running compared to standing. The authors also identified decreases in values parallel to time in faster running speeds indicative of a monosynaptic reflex following impact. It can be hypothesized that the central fatigue induced by prolonged running may further alter/decrease the value of PFM recruitment and also affect phasic recruitment predisposing both SUI and movement dysfunction.

This exciting new research on PFM EMG measurement during different running speeds established good reliability (ICC >0.75) within and during running positions (Luginbuehl *et al.*, 2016:122).

In terms of functional endurance, two of the three anterior musclegroup profiles that showed increases in post-exercise values were participants with SUI. Stress urinary incontinence is correlated with decreases in abdominal activity (2.3.). The abdominal testing position in unsupported sit has been shown to increase EMG activity in the PFM(Sapsford, 2008:1745). The hypothesis can be made that this increase in anterior muscle group activity may have been an effort to enhance PFM activity in the participants with SUI.

5.2.4. FUNCTIONAL ENDURANCE PROFILES

Millet & Lepers (2004:107) has identified isometric losses within the knee extensor muscles following prolonged running of at least two hours. Also both peripheral and central fatigue have been identified in female long-distance runners immediately after distances similar to the task used in this research (see 2.4.2). A decrease in the post-exercise profiles of the isometric functional tests were hypothesised initially. On the contrary, a noteworthy number of participant profiles displayed an increase in endurance (measured in seconds) within functional positions after the LSD. Even though none of the four (4) endurance profile-groups showed a statistical significant difference between baseline and post-exercise values (Chapter 4, Table 4) this increase in activity can be attributed to redistribution secondary to failure of the more tonic, local muscle groups (see 5.2.1). The increased activity could be to maintain stability that resulted in lower thresholds within the predominant *global stabilizers* given that any muscle can act as stabilisers and/or mobiliser at any time (Behm, 2015). With the pressure biofeedback profiles indicating the subsystem's inability to stabilise low load in both baseline and post-exercise profiles , the recruitment of *global mobilisers* to augment active core stability may have resulted in the increases within the functional profiles post-exercise (Chapter 2, Figure 2). The functional testing positions as prescribed by McGill *et al.* (1999) can however not distinguish between the individual stability system contribution to integrated functional stability.

The ability of the *global mobilisers* to transfer torque and momentum is conducive to the repetitive nature of running to assist in proximal stability under high loads (2.1.1.1.) However, should any mobiliser be recruited with the global stabilisers in acting in a local stability capacity, these muscles are subjected to supra-physiological loading and resulting dysfunctional movement. The muscles will present with increased inflexibility or shortening (Chapter 2, Figure 3) and this may serve as indication to which muscles are predisposed to overuse (Comerford & Mottram, 2001:19). The objective assessment of the global stability and mobility muscles in terms of range and flexibility should therefore be included in core-stability profiling, other than only interpreting statistical indicators in tests sensitive to identify change.

The decreases in post-exercise profiles can be contributed to failure to resist fatigue as endurance testing procedures have been found to be indicative of fatigue (Cairns *et al.,* 2005:10). Even though a degree of endurance loss is expected, it is unknown when structures will fail and not be able to maintain optimal kinetics. Follow-up research is needed to shed more light on the characteristics of stability structures at different intervals and its correlation to fatigue and injury.

Ten (n=10) profiles of the non-dominant lateral muscle group and posterior muscle groups and nine (n=9) of the anterior muscle group displayed decreases in post-exercise values. These decreases could have indicated either loss of endurance and thus muscle fatigue or domination by global muscles acting within a tonic capacity (5.2.1). Isometric loss of muscle strength after prolonged running (Millet & Lepers 2004:107) would be amplified by the loss of phasic recruitment by the global muscles then acting primarily within a stability capacity. Irrespective of these attributes, the endurance deficit in the profiles were clinically significant within the saggital plane (Chapter 4, Graphs 9 & 12). The increase in lower-limb excursions within this plane during running (Bruckner & Khan 2012:62) may place the kinetic chain at risk if movement in this plane lacks proximal stability.

The decrease in the values of the posterior post-exercise profiles, although not statistically significant (p=0.1909), are similar to the results by Granata & Gottipati (2008:1267) after a protocol to fatigue trunk extensors. The latter has been associated with increase in lumbar angulation with resulting low-back pain due to the stress-increase on the intervertebral structures (Schache *et al.* 2005:140). The angulation may be further increased by the decrease in eccentric ability of the anterior muscle-group to control pelvic excursion in the sagittal plane.

Should these alterations have taken place, the additional increases in axial rotation and lateral flexion during the “normal” biomechanics of running (see 2.2.), may be an explanation of the 60% lumbo-pelvic injuries found within this cohort (Chapter 4, Graph14).

The statistical significance values of the lateral,posterior and anterior muscle groups were also noticeably different from the dominant lateral group (Chapter 4, Table 4). The isometric nature of the lateral- and posterior testing position are similiar to those used by Leetun *et al.* (2004) and Nadler *et al.* (2000) who related these decreases in isometric strength to lower-limb injury causation. It might therefore also be considered as an explanation for the abundance of lower-limb injuries identified within this cohort (Chapter 4, Graph 14).

Previous research, including the pilot research on functional testing procedures (McGill *et al.,* 1999), found no statistical differences in baseline values between the dominant- and non-dominant side lateral muscle group. Eight of the 15 post-exercise profiles of the dominant-side lateral group however displayed an increase in endurance *after* exercise. This is in sharp contrast with the majority of the non-dominant side profiles that showed decreases, but is comparable to the side-to-side differences identified in previous research on female athletes with overuse injuries (Zifchock, Higginson, McCaw & Royer, 2008:898) . The question is whether the side-to-side difference correlates with injury within this group or with the dominant side's attempt to enhance stability in response to deficit on the non-dominant side. It is also plausable that the dominant side profiles just reflected an increased physiological ability of the dominant side to resist fatigue.

Considering the differences between the dominant- and non-dominant profiles in this research, prospective studies that correlate injury with core-characteristics should therefore identify injury with differentiation on dominance. This research only discuss core characteristics within the framework of risk of injury. No attempt on any correlation between core characteristics and injury was made.

The mean baseline value of all four (4) functional tests was considerably less that the normative values stipulated by McGill *et al.* (1999:943) (Chapter 4, Graph 13). The normative values was derived from a healthy, non-athletic cohort with a mean age of 21 years. Even though no direct comparison should be made, it could be reasoned that a healthy group of runners that average mileages of 62 kilometers per week in-season should demonstrate similar or better charactersitics for the purpose of comparison (Chapter 4, Graph 27).

The isometric nature of the McGill testing procedures as indicators of the *functional* endurance ability of runners is questionable as phasic recruitment during running is determined by tonic activity within functional positions (2.3.). Still, the low values in the baseline profiles compared to the norm questions the ability of the active core subsystem to resist fatigue induced by LSD training and competing in a marathon.

5.2.5. ACTIVE CORE STABILITY AND RISK OF INJURY

This research proposes the possibility of clinical neuromuscular mechanisms within the active core stability systems within the framework of injury causation in this cohort. The EMG profile changes reflected a possible redistribution of load within the local muscles that either presented as a decrease in EMG value (overuse and failure) or increase in EMG (redistribution to other regions of the muscle or an alteration in force direction). Failure/overuse could also reflect as decreases in post-exercise values or increases in co-activating muscles. The proprioceptive implication on normal biomechanics may predispose the process of movement dysfunction and resulting injury/recurrence of injury (Chapter 2, Figure 3).

The LSDs completed fell within the limits proven to induce fatigue that may alter the threshold of the entire active subsystem (Millet & Lepers, 2004:113). The low level of the post-exercise pressure biofeedback profiles could be speculated as indicative of a central fatigue. The loss of anticipatory tonic stabilisation required recruitment of the phasic global mobilisers secondary to a lowered threshold within these muscles. The increased activity within these muscles compensated for the lack of proximal stability and reflected within the post-exercise profiles as an increased ability to endure a functional position. The decreases in post-exercise profiles were speculated to be attributed to failure/fatigue, but the correlation to injury remains unknown.

Research has shown fatigue to furthermore alter GRF attenuation and altered running kinetics secondary to posterior muscle group fatigue (2.2.). The resulting postural/biomechanical adaptation in combination with the proprioceptive core-stability deficit predispose injury and injury-recurrence (Chapter 2, Figure 3). This rational is supported by the prospective study by Bliven and Anderson (2013:516) that established core stability deficit as precursor to knee injury. The predominant area of injury for this cohort was also the knee with a prevalence of 47%. (Chapter 4, Graph 14).

Other than how stability relates to injury, a loss in performance may also result from the global mobilisers acting within a stability/tonic capacity rather than producing torque (Comerford & Mottram, 2001:19). This will however not be discussed in further detail as it falls outside the framework of this research.

5.3. INTERNAL FACTORS OF RUNNING INJURY CAUSATION

5.3.1. THE LOWER LIMB KINETIC CHAIN

The proposed neuromuscular mechanism for the changes in the core profiles were related to injury causation within the model of movement dysfunction (Chapter 2, Figure 3). This mechanism identified the muscle charactersitics of the core as major internal risk of injury within this cohort as it was represented within the adjusted model of injury causation (Chapter 2, Figure 5).

A strong association exist between previous running injury and running injury causation (2.5.1.1). Research has indicated that experienced runners, such as the population in this research, suffer from less injuries. A noteworthy number of injuries within the lower-limb kinetic chain were however identified in this cohort (Chapter 4, Graph 14). This is in similar standing with previous research on running injuries that identified 90% of injuries within the lower-limb (Van Gent *et al.*, 2003). The knee was also the predominant area of injury in this research (47%)(Chapter 4, Graph 14). The systematic review by Van Gent *et al.* (2003:7) identified a similar 50% of long-distance runners to suffer from knee injuries. As is the case in this report, numerous researchers have identified neuromuscular mechanisms within the proximal stability musculature for knee injuries in female athletes (2.2.).

The influence of the 57% previous distal injuries (Chapter 4, Graph 14) on biomechanics and GRF attenuation within the kinetic chain also increase the risk of movement dysfunction and injury (2.2.)

Other than knee injury, twenty percent (20%) of participants had also undergone knee surgery (Chapter 4, Graph 15). A high prevalence of surgery existed within the lumbo-pelvic region of the cohort (20% lumbar, 40% pelvic) and together with the 40% occurence of abdominal surgery (Chapter 4, Graph 5), the kinetic chain of these runners may function at an increased risk of injury, especially as only 31% of participants included core specific training of the proximal structures in rehabilitation of these injuries (Chapter 4, Table 4). This is troublesome as 77% of the participants rehabilitated under supervision of a health professional such as a doctor, physiotherapist or biokineticist. This may reflect the conflicting views amongst clinicians on the importance of the core in management of patients. The readiness of the kinetic chain for loading is however ensured by increased sensitivity of the muscle spindles within the active subsystem (Kenney, Wilmore, & Costill, 2012:220). Core exercises to increase spindle activity has to start with neuromuscular activation that progresses to include functional core strength training (2.6.2.1.).

5.3.2. STRESS URINARY INCONTINENCE

Age, BMI, parity and mode of delivery falls within the category of internal risk factors within the adapted model of injury causation (Chapter 2, Figure 5) are associated with the functioning of the core and also predispose stress urinary incontinence (SUI)(2.3). Stress urinary incontinence falls within the description of running injury for the purpose of this research (2.3.).

Eighty-two percent (82%) of the female runners in this research could have had an increased risk of injury secondary to parity, with 70% of the parous participants speculating to have an even higher risk due to multiparity (Chapter 4, Graph 17). In terms of vaginal delivery, 50% of the parous participants also reported vaginal deliveries (Chapter 4, Graph 18). Conversely, only three participants reported SUI. The possibility of core stability deficit for these participants' SUI was identified and discussed in section 5.1.2.

This included adaptations within the abdominal muscle group. The high prevalence of abdominal surgery even in participants that did not present with SUI, may predispose SUI within the cohort if it was insufficiently rehabilitated post-surgery (2.3.)

The average age of this cohort was 43 years that is not regarded as an increased risk for running injury(2.6.1.2). Only three (3) participants were aged older than 50 years thus increasing risk of injury in them (2.6.1.2.). No correlations were made for the purpose of this study, but one (1) participant (aged 53) reported SUI and another (aged 58) mentioned SUI five years prior to participation in this research. Other than the neuromuscular contributions proposed for the participants in section 5.2., other physiological changes that may contribute to SUI fell beyond the scope of this research, but needed to be considered for interpretation purposes.

None of the participants that reported SUI or running injury measured above or below the normative value for BMI (Chapter 4, Graph 16) eliminating BMI as causative internal factor for this cohort. This is similar to the results by Taunton *et al.* (2003:243) who found BMI to be more relevant to running injuries in men.

This research has provided sufficient rational to include SUI sunder the umbrella of running injuries as the similarities in causative neuromuscular mechanisms (5.1.), risk factors and management in terms of core-stability is significant.

5.4. EXTERNAL FACTORS OF RISK OF INJURY

5.4.1. CONDITIONING

Continuing the discussion on risk of injury, conditioning can be categorised as an integrated internal and external causative factor of injury within the comprehensive model of injury causation (Chapter 2, Figure 5) and within the framework of core-stability. The intrinsic characteristics of the muscles secondary to conditioning are determined by the external specificity of the exercise modalities to enhance stability and running performance. This research has proposed an evidence-based rational to include especially neuromuscular training in conditioning of female runners (5.1).

Sixty-seven percent (67%) of participants included muscle conditioning in their training program(Chapter 4, Graph 19) . Thus 23% of the runners within this cohort could have been running with an increased risk of injury secondary to the absence of any training that my improve resistance of the lower-limb kinetic chain to fatigue and the possibility of movement dysfunction and injury. Even though the majority (73%) of the runners that icluded muscle conditioning included proximal muscle training, optimal neuromuscular activity of the local core muscles are a prerequisite to ensure adequate proprioception, not only during running, but during any movement (Chapter 2, Figure 3). Local neuromotor function, especially the PFM, determines phasic/global muscle activity regardless of the stage of conditioning/rehabilitation (2.3.). Only 53% included exercises modalities biased for neuromuscular recruitment such as physioball exercises whereas only 20% included pelvic floor exercises (Chapter 4, Graph 20). Participants that conditioned without optimal tonic stabilisation may therefore not only be at higher risk of running injury and recurrence of injury, but also injury during conditioning (Chapter 2, Figure 3 & 2.6.2.1).

The majority of participants (n=10) followed an endurance-based conditioning regimen of low weights at higher repetitions (Chapter 4, Figure 8). Even though this is specific to the demands of running, the addition of strength training may not only further augment stability via the force-transfer global mobilisers, but also enhance performance due to increased resistance to fatigue and the resulting low threshold adaptations (5.1.)

To conclude, forty-seven percent (47%) of the runners utilised conditioning exercises from allied health professionals such as physiotherapists and biokineticists. The media was identified as the other major source of exercises within this cohort (40%). This is troublesome as the complexity and importance of neuromuscular training in kinematics warrants careful instruction and prescription of exercise unlike the generalising of exercises for sporting disciplines within magazines. With neuromuscular rehabilitation falling especially within the scope of physiotherapists, the 20% minority that conditions under the care of physiotherapists is of even more concern and the reason should be explored whether it is a lack of knowledge or interest on the physiotherapists' side.

5.3.2. RUNNING-RELATED TRAINING

5.3.2.1. MILEAGE INCREASE

Very little consensus also exist between authors on the relationship between running-related training and injury (2.6.2.2.). There is however agreement on the sharp increase of mileage related to the risk of running injury (2.6.2.2.). Fifty-three percent (53%) of the participants could have had an increased risk of running injury secondary to sharp (non-specific) increases in weekly mileage (Chapter 4, Table 5). As suggested by Nielsen *et al.* (2012:70), 27% percent of the participants were potentially protecting themselves from injury with approximately 10% increase in weekly mileages. Strong evidence exist for increases in weekly mileage to be protective against sustaining knee injuries (Van Gent *et al.*, 2007:473). The results of this research supports the latter findings as all participants increased their weekly mileage, whereas 90% of the participants reported marked increases with the knee as the predominant area of injury (47%) (Chapter 4, Graph 14).

5.3.2.2. RUNNING FREQUENCY

The majority of the runners (80%) in the cohort trained for five or more days per week indicative of increased risk of running injury (2.6.2.2.). It is important to interpret days of running as it relates to weekly distances i.e. more days of running fewer miles may be protective against injury (Taunton *et al.* 2003:243). As no correlations were made for this research no conclusion is made in terms of running frequency and injury causation for this cohort.

5.3.2.3. WEEKLY TRAINING MILEAGE

The average training distance per week within the running season was 63 kilometers. This average means that participants utilized 90% of the oxidative system such as is indicated for endurance training over distances of 42.2 kilometers, which is the distance of marathons (2.6.2.2.). The specificity principle (2.6.6.2.) was upheld within this cohort, with none of the responding participants (n=14) training for less than an average of fifty (50) kilometers per week during the running season (Chapter 4, Graph 27).

However, only four (4) participants trained at a pace slower than their race pace. This over-utilisation of the aerobic and glycolitic systems results in decreased resistance to fatigue (2.6.2.2) and could therefore have predispose overuse injury due to proprioceptive deficit and resulting movement dysfunction (Chapter 2, Figure 3 & 2.1.1.2).

Even though the average training distance was 13 kilometers less per week in the off-season, two participants ran on average slightly more during the off-season while all participants ran continuously in a year (Chapter 4, Graph 27). The entire cohort could therefore run a considerable risk of injury secondary to continuous running (Van Gent *et al.*, 2007:473) and/or lack of periodisation. Other than the physiological benefits of periodisation, the necessity thereof also lies within mental recovery that relates to the central nervous system and therefore the neural subsystem of the movement system (Chapter 2, Figure 2 & 2.1.1.2) Especially in terms of *active* core stability during running, this and other psychosocial contributors must be addressed to augment resistance against what seems to be fatigue of a more central nature during prolonged endurance activities (2.4.2.).

5.3.3. RECOVERY

Closely related to the concept of periodisation, is the concept of recovery. There was a tendency within the cohort to recover after marathons, but not after LSD training (Chapter 4, Graph 28). Thirteen percent (13%) of participants did not engage in any recovery methods after LSD training whereas all participants recovered from marathon runs. Forty-seven percent (47%) of the participants either actively or completely rested for more than one day (24 hours) after a marathon, but none of the participants rested for longer than twenty-four (24) hours after an LSD. If one considers recovery from fatigue to be between two and five days (Petersen *et al.* 2007:394-395), the conclusion can be made that all participants continued training within a possible state of fatigue after LSD training. Likewise fifty-three percent (53%) trained whilst possibly fatigued after a marathon (Chapter 4, Graph 26).

Inadequate recovery from neuromuscular fatigue induced by prolonged eccentric activities such as running ignites movement dysfunction secondary to loss in proprioception (2.1.1.2.). This cohort was characterised by high average mileages both seasonal and off-season and the majority of the participants also did additional muscle conditioning. The absence of adequate recovery during running-related training therefore hypothetically could predispose the entire cohort to dysfunctional movement patterns and resulting injury.

Participants seemed to prefer complete rest to active rest in general (Chapter 4, Graph 26). This is contrary to the proposed benefits of active recovery in literature (2.6.2.4.). However lacking in evidence, active recovery supports the specificity principle during seasonal training(2.6.2.4.). On the other hand, complete rest within the off-season may prove valuable to ensure periodisation without comprimising specificity. No differentiation in seasonal preference was made for this research, but has merit for future enquiries on recovery.

5.3.4 EQUIPMENT AND ENVIRONMENT

With a variety of running shoes advocated and readily available, the majority of the participants (73%) wore a neutral running shoe (Chapter 4, Graph 25). Thirteen percent (13%) of participants respectively used minimalistic or anti-pronation shoes by choice. The protective effect of the latter two specifications on the kinetic chain can be either the "natural" decreased pronation moment with barefoot/minimalisic shoes within the external decrease in pronation moment provided by the anti-pronation shoe (Altman & Davis, 2012:247).

Irrespective of type of shoe, injury has been associated with delayed shoe change. The vast majority of the participants only changed their shoes on mileages higher than six hundred kilometers (600km+)(Chapter 4, Graph 26). Considering the average mileages, the shoe changes did not fall within the three months that have been suggested to predispose injury (2.6.2.3.). The remaining twenty percent (20%) of participants changed shoes according to their own preference which is in line with numerous researchers proposing a comfortable fit (2.6.2.3.).

Research on running shoes is limited, but the importance thereof is significant as an initial determant of GRF attenuation within the kinetic chain (2.2.). Considering the differences within the numerous running styles and therefore movement systems, this research supports a biomechanical assessment as proposed by Hreljac (2005:657) especially in the presence of proximal stability deficit.

Only one participant (= 7%) used a variety of running shoes (Chapter 4, Graph 25). The proposed risk of injury secondary to that is the alterations in kinematic parameters additional to changes in GRF. This is also the case in training on different running surfaces. Forty-eight percent (48%) of participants trained (running) on surfaces other than tarmac. (Chapter 4, Graph 24). Variability in running surfaces may protect from injury as a variety of changes occur within running kinematics thus limiting structural overuse (Schutte, 2016:8). Conversely sudden changes in running kinematics may incite supra-physiological loads predisposing injury. Specificity of training in terms of loading requires training on the competitive surface as the activation of movement happens on a central nervous system level (2.1.1.2.).

Sharp or sudden changes in running environment may therefore result in insufficient core-activation, compensation and movement dysfunction (Schutte, 2016:8) Therefore, training aimed at deloading of joints should be by means of cross-training rather than changing running surface (2.6.2.4.).

The majority of the participants (87%) however did train on the surface they competed on (Chapter 4, Graph 24). Again, this can be interpreted to be beneficial in terms of sport-specific training, but on the contrary it predisposes injury due to repetitive loading on a hard surface proven to elicit stress-related injury if not sufficiently conditioned (Schutte, 2016:2). Therefore, no conclusion in terms of environment and injury causation can be confidently infered in this research and no formal correlations were calculated.

CONCLUSION

The interpretation of the profiled results suggested possible neuromuscular mechanisms and adaptations that may predispose running-injury and SUI within the active lumbo-pelvic subsystem when exposed to a functional, sport-specific endurance activity. The neuromuscular adaptations were present in the integrated subsystem and not in isolation. This risk of injury , irrespective of stability deficit , is further increased in the presence of the numerous identified internal and external factors summarised within the comprehensive model of injury causation. This chapter concludes with the limitations identified in this research followed by further recommendations for future research on core-stability.

LIMITATIONS

In addition to some limitations identified in the previous sections, the small sample size was the major limitation of this research as it negatively influenced the strength of the data analysis (5.1.). This shortcoming was attributed to the limitations in determining the target population mentioned in 3.4.3. The lack of assistance and feedback from local running clubs contributed to the inability to accurately determine the size of the target population.

Contributing to the poor response rate, the participants also mentioned the duration of the measurement protocol after an LSD as a limiting factor. This limitation was expected in the use of an analytical study design (3.3) Participants also withdrew due to concerns of the measurements resulting in injury close to races.

Participants used early morning club runs as LSD. The finish of these routes is situated at a distance from the place of measurement. Due to safety concerns, the post-exercise testing was done as soon as possible but not directly after completion of the longrun. Participants were all tested within 30 minutes after the LSD was completed. The effect of possible recovery could however not be determined. Neuromuscular recovery can take place between 30 minute and several days after prolonged exercise. The first thirty (30 minutes) after cardiovascular exercise is also considered the golden window of recovery where nutritional replenishment of the depleted metabolic stores takes place (Du Toit, 2013).

This fell beyond the scope of the field of research, but should be considered in research utilising metabolic markers of fatigue.

The participants did not all use the same route to complete a functional endurance task for safety reasons. The implication thereof lies in the difference in environmental demands placed upon the musculature, especially on the neuromuscular characteristics investigated in this study (Schutte, 2016). Again, this should have a minimal effect on the outcome of this study as individual profiles were discussed and the routes are used in the runners' usual functional training programs.

This research was conducted with the absence of a control group. This was attributed to the duration of the research participation and invasive nature of the assessment of the pelvic floor musculature. Several research attempts aimed at the measurement of the pelvic floor in healthy subjects present with this particular limitation and similar small/no sample. Neither normative pressure biofeedback level nor EMG values have been proposed for either the PFM or the TrA. Also, the functional test normative values were derived from a non-sporting population (Grape *et al.*; 2009:369-399; McGill *et al.* 1999:941-943). This research investigated the effect of a functional endurance activity of on core muscle characteristics and inferences on the changes were made as it occurred within individual profiles and how regular exposure to this activity may relate to movement dysfunction and therefore injury.

Finally, apart from PFM EMG, the same researcher did not perform all measurements. The duration of the testing battery and the LSD necessitated multiple researchers to perform the testing procedures. Efforts were taken to minimalise the effect of this limitation on the reliability of data. (3.7.)

RECOMMENDATIONS

The proposed neuromuscular changes within the active core subsystem were deduced from the assumption of fatigue and the presence of internal and external risk factors of injury. Future research warrants investigation of these characteristics within a functional environment of defined and measured fatigue to determine the extent at which the active subsystem fails to resist fatigue. Measurement of these characteristics should also commence at different distance and speed intervals to identify the ability and efforts made by the active subsystem to augment stability.

This is supported by the changes identified in the PFM over short distances in the research by Lugenbiehl *et al.,* (2016).

To improve generalisability of findings on core stability activity, participants should also complete the same functional activity in terms of distance and environment/route especially since an increase in eccentric activity such as a route with hills may result in more significant neuromuscular adaptations in comparison to a flat route. For this reason distinction between novice and experienced as well as road and trial runner-populations may reveal interesting results.

Baseline measurement and post-exercise measurement should commence directly before and after completion of a functional activity to limit exposure to additional fatigue and recovery from fatigue respectively. This difficulty lies within practicality when completing long distances and using a battery of multiple tests. Large research teams and perhaps alternative testing procedures may overcome this hurdle.

The battery of tests used for profiling in this research was chosen as practical tests representing the different components of the active subsystem of the core. These tests are used within the clinical setting and have been proven to be reliable and valid. However, reliable and valid *functional* tests are still severely lacking. Future researchers should investigate existing and alternative testing procedures to assess the lumbo-pelvic core in a variety of sporting disciplines. This may be one step closer to determine normative values within a system necessary to ensure optimal movement and performance.

The significant number of external and internal risk factors of injury identified within the small sample of this research calls for further efforts to correlate these factors to core muscle characteristics. Larger samples will however be needed to correlate injury with both these factors and core- characteristics.

The controversy on core stability characteristics and the importance of core-stability in injury prevention and performance will persist well beyond completion of this research especially in the absence of a gold-standard testing protocol. All the above-mentioned considerations for future research should be done in the presence of a control group to offer either strong support or to negate already existing views.

CHAPTER 6

CONCLUSION

Contrary views remain on the significance of proximal/core stability both in sporting injury causation and in sporting performance. This study proposed possible neuromuscular mechanisms for the changes within the profiles after exposure to a functional activity of endurance proven in previous research to result in fatigue, especially central fatigue. This functional task forms an essential part of running-training and is frequently performed. The suggested neuromuscular adaptations might have indicated core stability deficit within the frame work of movement dysfunction predisposing injury/recurrence of injury. The high prevalence of especially lower-limb running injuries both in this and other research may therefore definitively relate to core-stability deficit.

The interpretation of the profiles drawn for the active lumbo-pelvic subsystem for this cohort of female long-distance runners identified both the inability of structures to resist fatigue and/or compensatory activity to augment stability. The latter was reflected in the increase in the majority of post-exercise profile values in the EMG and PBU. The neuromuscular mechanisms proposed for risk of injury are firmly supported both by research and in clinical practice. Either mechanism might have predispose movement dysfunction by either failure of the structures or supra-physiological loading/overuse of the structures. It is important to remember that the conclusions in this research were derived from profiles of uninjured runners. The proximal structures still displayed possible compensatory mechanisms to maintain stability in response to an endurance activity that runners perform on a weekly basis.

Numerous intrinsic and especially external running-related training factors were also identified especially previous injury and training related errors including insufficient recovery from LSD running. Despite the other mechanisms of injury brought about by these factors it remains unclear when these risk factors of injury will further necessitate proximal compensatory mechanisms to such an extent that it will result in complete failure of stability structures despite optimal conditioning strategies.

The profiles were compiled from non-functional testing positions. More specifically, the predominant tonic and transverse PFM characteristics may not have been properly represented in the absence of gravitational load. The need to establish valid and reliable functional core-stability testing procedures remains clear. It is unlikely that one single gold-standard test can display the integration of systems within the mobility-stability system. The applicability of profiling with a battery of tests as was used in this research may be more suitable to display and differentiate between core characteristics. The changes in the profiles secondary to the LSDs used in this research also indicated a higher possibility of central fatigue of the core muscles. This again reutterates the comprehensive integration of the neural and active subsystems and the holistic interdisciplinary management of core-stability.

Likewise, excluding the core in rehabilitation and/or general conditioning from injury further increases risk of injury recurrence anywhere within the kinetic chain especially in the presence of other causative factors for injury. The intricate adaptations and system integrations to augment stability were seen in the variability in differences between *individual* baseline and post-exercise profiling. Core-stability assessment and management strategies should therefore be applied in how it is applicable to risk of injury within the individual athlete.

To conclude, this research in conjunction with existing literature, supports inclusion of the proximal lumbo-pelvic core in strategies for injury prevention and should be included in general conditioning and injury rehabilitation.

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ADDENDUM A

INFORMATION LETTER

The lumbo-pelvic core: Profiles of female long-distance runners

Researcher: **Ms. Lindie Pool (nee Vorster)**

B.Sc. Physiotherapy (UFS)

University of the Free State

Advisor: **Ms. Corlia Brandt**

M.Sc. Physiotherapy (UFS)

Department of Physiotherapy

University of the Free State

Lindie Vorster is a qualified and registered physiotherapist. This study forms part of her Masters in Clinical Sports Physiotherapy at the University of the Free State. The study has been approved by an accredited ethics committee.

ELIGIBILITY

- Female runners of at least 18 years of age who have been running for twelve (12) months or longer (non-novice) and who runs at least 30 km per week.
- Prospective participants must be proficient in English or Afrikaans with sufficient literacy to complete a questionnaire in writing in either language.
- Be registered with an Athletics Free State Running Club in Bloemfontein.
- Prospective participants who are pregnant or within 6 weeks after delivery will not be eligible.
- Injured female runners will not be considered eligible. This includes any ailment receiving medical attention or any ailment that rendered the runner unable to do usual training for one week (7 days).
- Prospective participants must have completed a marathon within a qualifying time of five (5) hours within twelve (12) months prior to the study.

AIMS

The study will also evaluate other risk factors of injury such as training, equipment and personal injury specifics. The aim thereof is to be able to compile a profile of a runner. The profile may reflect changes in core-muscle activity as well as additional factors that may contribute to injury. The identified factors and muscle dysfunction can then be addressed in terms of prescribed muscle conditioning programs and suitable adjustments. This is aimed at lowering risk of injury especially during fatiguing activities. Optimal core-functioning have also been demonstrated to improve performance.

REQUIREMENTS

If you agree to be part of the research study, you will be asked to:

1. Undergo measurement of your height and weight to determine your body mass index (BMI) as it is proven to influence pelvic floor muscle functioning.
2. Complete a questionnaire: Questions will focus on previous injury, childbirth history, training, running history and specifics as well as information on equipment used in running.
3. Undergo functional muscle testing: The pelvic/low back/trunk core muscles will be tested in three, low load functional positions that will be demonstrated to you. The position will be held and measured in seconds until quality of movement is lost. Each movement will be tested three times (3x).
4. Undergo biofeedback muscle testing of:
   - The pelvic floor muscles. You will be instructed how to insert a comfortable sterile probe into the vagina. This will be done in a private room and at no time will any part of the body be exposed. The researcher will then give instruction on a pelvic floor muscle contraction. The biofeedback device will register a measurement that the researcher will record. The measurement will be repeated three times (3x). You will then remove and dispose of the covering of the probe in private as instructed.
   - The Transversus Abdominus muscle: The researcher will place electrodes on your lower stomach and a biofeedback pillow in the small of your back.

You will then be instructed on the desired contraction of the lower stomach muscles. The contraction will be measured in a variety of low load positions while lying on your back which will be explained to you.

- After initial measurement you will be asked to complete any 24+km kilometer longrun of your choice. You may complete this task at your own pace and with no time limit and as part of a club run. You may also at any time withdraw from the run or any of the research related activities.
- Following the longrun all initial *physical* measurements will be repeated in order to compare the results before and after the longrun.

Please note:

- All physical measurement will be done in a private consultation area.
- The duration of your participation, excluding the longrun, is estimated at two hours.

DURATION OF PARTICIPATION

The duration of your participation in this study is estimated, but not limited to two (2) hours apart from the longrun.

BENEFITS

You will directly benefit from being in this study as a scientific and comprehensive assessment of your core stability muscles will be done. Also, comprehensive local and global core-stability has not been widely researched. Therefore your participation will contribute to gaining further knowledge thereof.

RISKS

The researcher has taken steps to minimize the risks of this study. Even so, you may still experience problems usually pertaining to a long run. Testing procedures used in this study have very few side-effects, but the researchers are careful to avoid it. These risks may include the following:

- Loss of privacy. The invasive testing method of the pelvic floor will be done with the utmost professionalism and all testing will be done in a closed private room. Personal information is asked in the questionnaire.
- Sustaining injury during the longrun. Even though you will complete the distance at your own pace without time limits and all measures will be taken to ensure a suitable tarmac route, unforeseen problems may arise. You will also be required to see to your nutritional and hydrating needs during the run.
- Muscle soreness. Even though safe and of low load, the repetitive nature of functional testing may result in mild muscular stiffness and soreness, though it is not expected.

Please tell the researcher about any injuries, side effects, or other problems that you may develop during this study. You should also inform your regular health care provider. Any management or costs involved remain your responsibility. By signing this form, you do not give up your right to seek payment if you are harmed as a result of being in this study.

COMPENSATION

In gratitude for your kind participation in the study, you will receive a cold beverage after completion along with a pair of running socks.

CONFIDENTIALITY

All information gathered during the study will be treated as confidential. Your name will be assigned to a code. This is necessary for comparison of data before and after the run and to allow the researcher to convey to participants their individual results should they request it in writing. Other than the researcher, the information will also used by the Department of Biostatistics of the University of the Free State for data analysis. The list will be kept safe by only the researcher.

PUBLISHING AND PROTECTION OF INFORMATION

The researcher plans to publish the results of this study, but will not include any information that would identify you. There are some reasons why people other than the researchers may need to see information you provided as part of the study. This includes organizations responsible for making sure the research is done safely and properly, including the University of the Free State's Faculty of Health Sciences' Committee of Ethics.

To keep your information safe, the researcher will keep all documented data in a locked safe. The researcher will retain the data for three (3) years from the date of measurement. The data may be made available to other researchers for other studies following the completion of this research study, but will not contain information that could identify you. The researchers will dispose of your data by burning the documented data.

VOLUNTARY PARTICIPATION

Participating in this study is completely voluntary. Even if you decide to participate now, you may change your mind and stop at any time. If you decide to withdraw early, all data pertaining to you will be kept in a locked safe until completion of the study after which it will be burnt. Again, should withdrawal be due to injury or side-effects of the research, please also discuss it with your healthcare provider.

If significant new knowledge is obtained through the course of the research which may relate to your willingness to continue participation, you will be informed.

IMPORTANT CONTACT DETAILS

If you have questions about this research, including questions about scheduling or your compensation for participating, you may contact *Lindie Vorster* at 051 433 4243 / 0711238241.

If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the Faculty of Health Science Ethics Committee of the University of the Free State:

Mrs (HS) Henriette Strauss OR *Mrs (J) Jemima Du Plessis*
Tel: +27 (0) 51 405 2821/12
Fax: +27 (0) 51 444 4359

You will be given a copy of this document for your records and one copy will be kept with the study records. Be sure that questions you have about the study have been answered and that you understand what you are being asked to do. You may contact the researcher if you think of a question later.

The lumbo-pelvic core: Profiles of female long distance runners

Navorser: **Me. Lindie Pool (neè Vorster)**

B.Sc. Fisioterapie (UV)

Universiteit van die Vrystaat

Adviseur: **Ms. Corlia Brandt**

M.Sc. Fisioterapie (UV)

Department Fisioterapie

Universiteit van die Vrystaat

Lindie Pool is 'n gekwalifiseerde en geregistreerde fisioterapeut. Hierdie studie vorm deel van haar Meestersgraad in Kliniese Sportfisioterapie aan die Universiteit van die Vrystaat. Die studie is goedgekeur deur 'n geakkrediteerde etiese kommitee.

INSLUITINGS KRITERIA

- Vroulike drawwers vanaf 18-jarige ouderdom wat vir ten minste twaalf (12) maande aktief draf (nie-beginner) en minstens 30 km. per week draf.
- Voornemende deelnemers moet taalvaardig wees in Afrikaans of Engels met die nodige geletterdheid om 'n vraelys in enige van hierdie taalkeuses in skrif te voltooi.
- Geregistreerd wees by 'n hardloopklub in Bloemfontein wat geakkrediteer is by Atletiek Vrystaat.
- Swanger dames asook dames binne 6 weke ná hul geboorte geskenk het sal nie oorweeg word vir deelname aan die studie nie.
- Vroulike drawwers met beserings sal nie ingesluit word by die studie nie. Dit sluit in enige pyn of ongemak wat mediese behandeling ontvang en/of wat gewone oefening van die drawwer verhoed vir sewe (7) dae.
- Voornemende deelnemers moet ook binne twaalf (12) maande van aanvangs van die studie 'n marathon voltooi het binne die kwalifiserende tyd van vyf (5) ure.

DOELWITTE

Die studie sluit ook in evaluasie van ander risiko faktore van hardloop-beserings. Dit behels oefeningsprogramme, toerusting en persoonlike geskiedenis van beserings. Die doel daarvan is om 'n profiel van 'n drawwer saam te stel. Hierdie profiel mag veranderinge in die spieraktiwiteit van die "core" aandui sowel as ander faktore wat mag bydra tot risiko van besering. Hierdie kwessies kan dan aangespreek word en die "core" verbeter word deur middel van aanpassing van of riglyne vir oefening. Die doel is om risiko van besering te beperk vernaam tydens vermoeiende aktiwiteit soos 'n "longrun". Optimale werking van die "core" kan ook prestasie bevoordeel.

VEREISTES

Sou u instem om deel te wees van die navorsing studie, gaan die volgende van u vereis word:

1. Meting van u gewig en lengte om u liggaamsgewig-indeks ("BMI") te bereken. Dit is bewys dat dit u pelviese-vloer spiere kan beinvloed.
2. Voltooi van 'n vraelys: Vrae gaan fokus op vorige besering, geboorte-geskiedenis, oefening, inligitng oor u drafprogram- en geskiedenis en die toerusting wat gebruik word.
3. Funksionele spiertoetsing: Die spiere van die pelviese- romp- en lae rug "core" gaan getoets word in drie, lae-lading funksionele posisies wat aan u gedemonstreer sal word. Die posisie word behou tot dat die kwaliteit van die beweging verlore gaan en dit word in sekondes gemeet. Elke toets word drie keer (3x) herhaal.
4. Bioterugvoer spiertoetsing van:
    - Die pelviese-vloer spiere. Die navorser sal u wys hoe om 'n gemaklike en steriele elektrode in u vagina te plaas. U doen dit self in 'n privaatkamer en op geen tydstip sal enige deel van u liggaam ontblot wees nie. Die navorser sal dan instruksies gee rakende 'n pelviese-vloer kontraksie. Die bioterugvoer apparaat registreer dan 'n lesing wat die navorser sal aanteken.

Dit word drie maal (3x) herhaal. U sal dan instruksie ontvang oor hoe om die elektrode self te verwyder en die oortreksel weg te gooi.

- o Die Transversus Abdominus spier: Die navorser sal elektrodes op u laer-maagspiere plaas sovel as ‘n bioterugvoer kussing in die holte van u lae rug plaas. U sal dan instruksie ontvang rakende die verlangde kontraksie van die laer-maagspiere. Hierdie kontraksie gaan in ‘n verskeidenheid lae-lading posisies getoets word terwyl u op u rug lê. Elke posisie sal aan u verduidelik word.

5. Na voltooiing van die metings sal u gevra word om ‘n “longrun” te voltooi van u keuse van 24+ kilometer. U mag hierdie taak uitvoer teen ‘n pas van u keuse en sonder enige tyd limiet en ook as deel van ‘n “clubrun”. Ter eniger tyd mag u onttrek van hierdie aktiwiteit of enige aktiwiteit rakende die studie.
6. Na afloop van die “longrun” taak gaan alle *fisiese* meting herhaal word in orde om ‘n vergelyking te kan tref met die meting voor die “longrun”.

Let wel:

- Alle fisiese meting sal gedoen word in ‘n private konsultasie area.
- Die tydsduur van u deelname, buiten die draf, sal meestens twee ure beloop.

TYDSDUUR VAN DEELNAME

U deelname aan hierdie studie sal ongeveer 2 ure neem, maar is nie beperk tot 2 ure nie. Dit sluit alle toets prosedures in.

VOORDELE

U sal ‘n direkte voordeel trek uit u deelname aan die studie deurdat ‘n wetenskaplike en volledige evaluering van u “core” spiere en risikofaktore gedoen word. Daar is ook steeds ‘n leemte in navorsing rakende die lokale en globale “core” stabiliseerders. U deelname is dus ‘n waardevolle bydrae tot nuwe insig rondom die “core”.

RISIKO

Die navorser het stappe geneem om risikos rakende die studie te minimaliseer. Nogtans mag probleme tydens die "longrun" en fisiese toets-prosedures opduik. Laasgenoemde het min tot geen bekende newe-effekte, maar die navorser sal steeds versigtig te werk gaan om dit te vermy.

Risiko mag insluit:

1. Verlies aan privaatheid. Die indringende metode van die pelviese-vloer toetsing sal met uiterste proffesionalisme hanteer word in 'n privaat kamer. Persoonlike inligitng word ook gevra in die vraelys.
2. 'n Besering tydens die "longrun". Die roete sal afgemerk word op 'n gepasde teerpad en u mag dit voltooi teen 'n pas wat vir u gemaklik is en sonder enige tyd limiet. Onverwagte problem en beserings mag wel voorkom. U gaan ook verantwoordelik wees vir u eie voedings- en hidrasie benodighede tydens hierdie taak.
3. Spier-teerheid: Alhoewel veilig en laag in lading, mag die herhaalende aard van die toets-prosedures lei tot matige spier-teerheid. Dit word egter nie verwag nie.

U moet asseblief die navorser inlig rakende enige beserings, newe-effekte en ander probleme wat mag opduik tydens die studie. U moet ook asseblief u dokter of mediese diensverkaffer daarvan inlig. U bly egter verantwoordelik vir hantering en kostes daaraan verbonde. U versuim egter nie u reg om vergoeding te vereis sou u benadeel word deur direkte toedoen van die studie nie.

VERGOEDING

U sal 'n koeldrank en 'n paar hardloop-sokkies ontvang om u te bedank vir u deelname aan die studie. U sal ook na afloop van die voltooiing van die navorsingsprojek 'n verslag ontvang waar u eie resultate met u bespreek word en moontlike risikofaktore wat tot besering kan lei, aangedui sal word.

VERTROULIKHEID

Alle inligting wat versamel word tydens die studie sal as streng vertroulik hanteer word. ‘n Unieke kode sal aan u naam toegewys word. Dit is nodig om sodoende die data voor en na afloop van die “longrun” draf te vergelyk. Dit is ook nodig sou deelnemers hul persoonlike resultate skriftelik aanvra. Die data gaan verwerk word deur die Departement Biostatistiek aan die Universiteit. Die lys sal in die navorser se besit bly vir veilige bewaring.

PUBLIKASIE EN BESKERMING VAN INLIGTING

Die navorser beplan om die resultate van die studie te publiseer. Geen inligting wat u kan identifiseer sal egter gepubliseer word nie. Daar is verskeie redes waarom ander partye toegang het tot inligting rakende die studie. Hierdie partye sluit in organisasies verantwoordelik vir die oorsig van veilige en etiese navorsing. Die Etiese Kommitee van die Fakulteit Gesondheidswetenskappe aan die Universiteit van die Vrystaat oorsien hierdie studie.

Die navorser gaan vir ‘n periode van drie (3) jaar u inligitng in ‘n kluis bewaar. Hierdie data mag wel vir opvolgstudies bekend gemaak word, maar sal geen inligitng bevat wat u kan identifiseer nie. Data sal dan na drie (3) jaar verbrand word.

VRYWILLIGE DEELNAME

Deelname aan die studie is geheel vrywillig. Selfs sou u nou besluit om deel te neem, mag u enige tyd van plan verander en staak. Sou u kies om te onttrek van die studie , sal alle data wat reeds ingesamel is veilig bewaar word in ‘n kluis tot die studie voltooi is. Daarna sal dit verbrand word. Weereens, sou u onttrek weens ‘n besering of newe-effek van die studie, bespreek dit asseblief met u dokter/ mediese diensverkaffer. U sal in kennis gestel word sou beduidende nuwe inligting deur die verloop van die studie opduik wat u bereidwillige deelname mag beinvloed.

BELANGRIKE KONTAK BESONDEREHEDE

Sou u enige verdere inligting vereis of vrae het rakende die studie, insluitend die skedule of vergoeding, kontak asseblief die navorser: *Lindie Vorster* by 051 433 4243 / 0711238241.

Sou u vrae hê rakende u regte as deelnemer, inligting verlang of besware wil opper rakende enige aspek van die studie, skakel die Etiese Kommitee van die Departement Gesondheidswetenskappe aan die Universiteit van die Vrystaat sou u dit nie met die navorser wil bespreek nie.

Kontak persone:

Me. (HS) Henriette Strauss OR *Me. (J) Jemima Du Plessis*
Tel: +27 (0) 51 405 2821/12
Faks: +27 (0) 51 444 4359

U sal 'n afskrif ontvang van hierdie dokument vir u rekords en 'n afskrif word gehou in die studie rekords. Wees asseblief seker dat vrae wat u gehad het rakende die studie beantwoord is en dat u duidelik verstaan wat van u verwag word. U kan die navorser kontak sou u later nog inligting verlang.

ADDENDUM B

RESEARCH APPROVAL: ETHICS COMMITTEE

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Research Division
Internal Post Box G40
☎(051) 401-7795
Fax (051) 4444359

E-mail address: EthicsFHS@ufs.ac.za

Ms M Marais

2015-03-10

REC Reference nr 230408-011
IRB nr 00006240

MS L VORSTER
DEPT OF PHYSIOTHERAPY
FACULTY OF HEALTH SCIENCES
UFS

Dear Ms Vorster

ECUFS NR 11/2015 **DEPT OF PHYSIOTHERAPY**

PROJECT TITLE: LUMBO-PELVIC CORE STABILITY: PROFILES OF FEMALE LONG DISTANCE RUNNERS

1. You are hereby kindly informed that, at the meeting held on 03 March 2015, the Ethics Committee approved the above project after all conditions have been met.

2. Committee guidance documents: Declaration of Helsinki, ICH, GCP and MRC Guidelines on Bio Medical Research. Clinical Trial Guidelines 2000 Department of Health RSA; Ethics in Health Research: Principles Structure and Processes Department of Health RSA 2004; Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa, Second Edition (2006); the Constitution of the Ethics Committee of the Faculty of Health Sciences and the Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines.

3. The Committee must be informed of any serious adverse event and/or termination of the study.

4. Any amendment, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

5. A progress report should be submitted within one year of approval of long term studies and a final report at completion of both short term and long term studies.

6. Kindly use the ETOVS/ECUFS NR as reference in correspondence to the Ethics Committee Secretariat.

Yours faithfully

DR SM LE GRANGE
CHAIR: ETHICS COMMITTEE

cc Ms C Brandt

ADDENDUM C

INFORMED CONSENT

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

TOESTEMMING TOT DEELNAME AAN NAVORSING

Jy is gevra om deel te neem aan ‘n navorsingsprojek.

Lindie Pool (neè Vorster) het u ingelig rakende die projek.

Jy kan Lindie kontak by 051 4334243 or 0711238241 sou jy enige vrae rakende die navorsing het of enige besering opgedoen het as gevolg van prosedures tydens die navorsing.

U kan die sekretariaat van die Etiek Kommitee van die Fakulteit Gesondheidswetenskappe, UV kontak by (051) 4052812 sou u enige vrae het rakende u regte as deelnemer.

U deelname is vrywillig en u sal nie gepenaliseer of benadeel word sou u weier om deel ten neem of om u deelname te termineer nie

U ontvang ‘n getekende inligtingstuk wat bevestig dat u instem en kies om deel te neem.

Die navorsing is aan my skriftelik verduidelik en ek verstaan die inligting soos hierbo uiteengesit. Ek verstaan my deelname aan die studie beteken dat ek vrywillig instem om deel te neem.

______________________ ___________________

Handtekening deelnemer Datum

……………………………

Naam en Van

______________________ ___________________

Handtekening navorser Datum

CONSENT TO PARTICIPATE IN RESEARCH

You have been asked to participate in a research study.

You have been informed about the study by Lindie Vorster.

You may contact Lindie Vorster at 051 4334243 or 0711238241 any time if you have questions about the research or if you are injured as a result of the research.

You may contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research subject.

Your participation in this research is voluntary, and you will not be penalized or lose benefits if you refuse to participate or decide to terminate participation.

If you agree to participate, you will be given a signed copy of this document as well as the participant information sheet, which is a written summary of the research.

The research study, including the above information has been described to me. I understand what my involvement in the study means and I voluntarily agree to participate.

______________________ ___________________

Signature of Participant Date

______________________ ___________________

Signature of Researcher Date

ADDENDUM D

CONFIDENTIALITY AGREEMENT RESEARCH ASSISTANTS

Research Assistant Confidentiality Agreement

Lumbo-pelvic core stability: Profiles of female long-distance runners

I, Maretha du Toit, agree to assist the primary investigator, Lindie Pool, with this study by performing the Pressure Biofeedback Test and Functional Endurance Tests. I agree to maintain full confidentiality when performing these tasks.

Specifically, I agree to:

1. keep all research information shared with me confidential by not discussing or sharing the information in any form or format (e.g., disks, tapes, transcripts) with anyone other than the primary investigator;
2. hold in strictest confidence the identification of any individual that may be revealed during the course of performing the research tasks;
3. not make copies of any raw data in any form or format (e.g., disks, tapes, transcripts), unless specifically requested to do so by the primary investigator;
4. keep all raw data that contains identifying information in any form or format (e.g., disks, tapes, transcripts) secure while it is in my possession. This includes:
   - keeping all digitized raw data in computer password-protected files and other raw data in a locked file;
   - closing any computer programs and documents of the raw data when temporarily away from the computer;
   - permanently deleting any e-mail communication containing the data; and
   - using closed headphones if transcribing recordings;
5. give, all raw data in any form or format (e.g., disks, tapes, transcripts) to the primary investigator when I have completed the research tasks;
6. destroy all research information in any form or format that is not returnable to the primary investigator (e.g., information stored on my computer hard drive) upon completion of the research tasks.

Signature of research assistant M du Toit.

Date: 16 January 2016

Printed name of primary investigator: Lindie Pool

Signature of primary investigator Pool.

Date: 16 January 2016

RESEARCH ASSISTANT CONFIDENTIALITY AGREEMENT

Lumbo-pelvic core stability: Profiles of female long-distance runners

I, Ronel Labuschagne, agree to assist the primary investigator, Lindie Pool, with this study by performing the Functional Endurance Tests. I agree to maintain full confidentiality when performing these tasks.

Specifically, I agree to:

1. keep all research information shared with me confidential by not discussing or sharing the information in any form or format (e.g., disks, tapes, transcripts) with anyone other than the primary investigator;

2. hold in strictest confidence the identification of any individual that may be revealed during the course of performing the research tasks;

3. not make copies of any raw data in any form or format (e.g., disks, tapes, transcripts), unless specifically requested to do so by the primary investigator;

4. keep all raw data that contains identifying information in any form or format (e.g., disks, tapes, transcripts) secure while it is in my possession. This includes:
   - keeping all digitized raw data in computer password-protected files and other raw data in a locked file;
   - closing any computer programs and documents of the raw data when temporarily away from the computer;
   - permanently deleting any e-mail communication containing the data; and
   - using closed headphones if transcribing recordings;

5. give, all raw data in any form or format (e.g., disks, tapes, transcripts) to the primary investigator when I have completed the research tasks;

6. destroy all research information in any form or format that is not returnable to the primary investigator (e.g., information stored on my computer hard drive) upon completion of the research tasks.

Signature of research assistant ____________________

Date: 16 January 2016

Printed name of primary investigator: Lindie Pool

Signature of primary investigator Pool ____________________

Date: 16 January 2016

ADDENDUM E

QUESTIONNAIRE

OFFISIëLE GEBRUIK

Identifikasie nommer

1	2

Naam: ....

Instruksies

Merk asb. u antwoord in die gepasde blokkie met 'n "X"
Meer as een antwoord mag gemerk word
Antwoorde word nie geag as "reg" of "verkeerd" nie
Sou u antwoord nie weerspieël word nie, merk asseblief die "ander" opsie
 en verstrek u antwoord
U mag vrae uitlos wat u nie wil beantwoord nie
U antwoorde beinvloed geensins u verhouding met die navorser of instansie nie

AMPTELIKE GEBRUIK

Vraag 1

OUDERDOM		
.................................jaar	3	4

Vraag 2

VLAK VAN HARDLOOP DEELNAME. merk SLEGS een		**5**
1. As ontspanning		
2. Kompeterend (kompeteer in wedlope)		
3. Professioneel		
4. Elite (nasionaal/internasionaal)		
5. Ander (spesifiseer asseblief)		

....

....

Vraag 3

HET U ENIGE VORIGE CHIRURGIE ONDERGAAN? merk ALLES toepaslik		
1. Vorige abdominale chirurgie		6
2. Vorige spinaal chirurgie		7
3. Vorige heup chirurgie		8
4. Vorige knie chirurgie		9
5. Vorige pelviese chirurgie		10
6. Geen		11
7. Ander (spesifiseer asseblief)		12

....

....

Vraag 4

LEI U AAN ENIGE MEDIESE TOESTANE WAT U SPIERE/GEWRIGTE AFFEKTEER?
merk ALLES toepaslik

1. Artritiese toestande (bv. Rheumatoïde ,osteoarthritis, lupus)		13
2. Osteoporose		14
3. Geen		15
4. Kroniese gebruik van kortisoon		16
5. Ander (spesifiseer asseblief)		17

…………………………………………………………………………

…………………………………………………………………………

Vraag 5

HET U GEBOORTE GEGEE? 18
Merk SLEGS een

1. Ja, normale geboorte	
2. Ja, keisersnit	
3. Ja, beide keisersnit en normale geboorte	
4. Nee	

Vraag 5.1

INDIEN U "JA" GEANTWOORD HET OP VRAAG 5, 19
HOEVEEL KEER HET U GEBOORTE GEGEE?
(Indien "nee" gaan voort na Vraag 6) ***merk SLEGS een***

1. EEN (1) KEER	
2. TWEE (2) OF MEER KEER	

Vraag 6

DUI ASB. AAN VORIGE AREAS VAN BESERING. (LET WEL: BESERING VERWYS NA 'n BESERING OF PYNLIKE KLAGTE WAT U WEERHOU HET VAN 7 DAE VAN GEWONE HARDLOOP). ***merk ALLES toepaslik***
INDIEN GEEN VORIGE BESERING, ASB. GAAN VOORT NA VRAAG 8

1. Lae rugpyn/besering		20
2. Heup pyn/besering		21
3. Pelviese en/of lies pyn/besering		22
4. Knie pyn/besering		23
5. Enkel pyn/besering		24
6. Voet pyn/besering		25
7. Geen vorige besering		26
8. Ander (asseblief spesifiseer)		27

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Vraag 7

WATTER TIPE REHABILITASIE HET U GEDOEN VIR DIE BESERINGS IN VRAAG 6?
merk ALLES toepaslik.
INDIEN GEEN VORIGE BESERING GAAN VOORT NA VRAAG 8

1. Ek het algehele oefeninge vir die beseringsarea gedoen		28
2. Ek het spesifieke oefeninge gedoen vir die area asook maag-, rug en beenspiere		29
3. Ek het professionele hulp ingewin (b.v. Fisioterapeut, biokinetikus, dokter)		30
4. Ek het weer begin draf soos die pyn/besering toegelaat het		31
5. Rus		32
6. Ander (asseblief spesifiseer)		33

....

....

Vraag 8

WANNEER ERVAAR U OEFENINGS-INKONTINENSIE (URIENE LEK TYDENS *OEFENING)?merk ALLES toepaslik*

1. Tydens "long runs", marathonne/ultr-marathonne		34
2. Gedurende oefeninge met gewigte/weerstands-oefeninge		35
3. Gedurende enige oefening/draf		36
4. Gedurende alledaagse aktiwiteite		37
5. Ek lei nie aan oefenings-inkontinensie nie		38
6. Ander (spesifiseer asseblief)		39

....

....

Vraag 9

DUI ASSEBLIEF AAN U TIPE HARDLOOP-SKOEN.
merk ALLES toepaslik

1. Neutraal		40
2. Minimalistiese skoen (b.v. Newton)		41
3. Ek gebruik verskeie skoene		42
4. Anti-pronasie skoene		43
5. Ander (spesifiseer asseblief)		44

....

....

Vraag 10

OP WATSE AFSTAND VERVANG U SKOENE?
merk SLEGS een

45

1. 200-400 kilometer	
2. 400-600 kilometer	
3. 600 +kilometer	
4. Ek verander skoene na gelang gevoel met draf	
5. Ander (asseblief spesifiseer)	

....

....

Vraag 11

OP WATTER OPPERVLAKTE DRAF U TYDENS OEFENING . merk ALLES toepaslik		
1. Teerpad		46
2. "Off-road" soos grondpad of roetes		47
3. Enige oppervlakte		48
4. Ek varieer tussen oppervlaktes		49
5. Gras		50
6. Ander (spesifiseer asseblief)		51

....

....

Vraag 12

HOEVEEL KILOMETER (GEMIDDELD) DRAF U ***PER WEEK*** **IN DIE LAASTE 6 WEKE VOOR 'n WEDLOOP?**

..............................kilometer

52	53	54

Vraag 13

HOEVEEL DAE PER WEEK DRAF U TYDENS DIE "DRAF-SEISOEN"? merk SLEGS een		55
1. 7 dae/week		
2. 5-6 dae/week		
3. 3-4 dae/week		
4. 1-2 dae/week		

Vraag 14

HOE VERHOOG U WEEKLIKSE KILOMETERS TYDENS VOORBEREIDING? Merk ALLES toepaslik		
1. Ek dra een (1) ekstra dag per week		56
2. Ek voeg meer as een (1) dag by per week		57
3. Ek verhoog geleidelik kilometers met ongeveer 10% weekliks		58
4. Ek draf 'n ekstra sessie per dag		59
5. Ek verhoog sekere dae se kilometers redelik skerp		60
6. Ander (asseblief spesifiseer)		61

....

....

Vraag 15

WAT IS U ***GEMIDDELDE*** SPOED TYDENS 'n "LONGRUN"? **(AFSTANDE 25+ KILOMETER)?** ***Merk SLEGS een***		62
1. 4 - 5 minute per kilometer		
2. 5 - 6 minute per kilometer		
3. 6 - 7 minute per kilometer		
4. 7 - 8 minute per kilometer		
5. 8+ minute per kilometer		
6. Ander (asseblief spesifiseer)		

....

....

Vraag 16

WAT IS U GEMIDDELDE SPOED TYDENS 'n MARATHON? merk SLEGS een		63
1. 4 - 5 minute per kilometer		
2. 5 - 6 minute per kilometer		
3. 6 - 7 minute per kilometer		
4. 7 - 8 minute per kilometer		
5. 8+ minute per kilometer		
6. Ander (asseblief spesifiseer)		
....		
....		

Vraag 17

OEFENINGE IN U PROGRAM ANDERS AS DRAF. Merk ALLES toepaslik		
1. "Cross-training" (b.v. "spinning", fietsry, swem)		64
2. Voorbereiding vir ander "endurance" wedlope (b.v. driekamp, fiets)		65
3. Muscle training (e.g. Weights, Pilates, physic-ball at the gym or home)		66
4. Geen, ek draf net		67
5. Ander (asseblief spesifiseer)		68
....		
....		

Vraag 18

WATSE TIPE SPIER VERSTERING DOEN U? merk ALLES toepaslik		
1. "Squats" en "lunges"		69
2. Abdominale (maagspier) oefeninge		70
3. Fisio-bal oefeninge		71
4. Spronge en trappe-oefeninge		72
5. Pelviese vloer oefeninge		73
6. Rondte-baan ("circuit") oefeninge vir die hele lyf		74
7. Geen spierversterking		75
8. Ander (asseblief spesifiseer)		76
....		
....		

Vraag 19

HOE VERSTERK U SPIERE? Merk ALLES toepaslik		
1. Hoë herhalings ("reps") met ligte en/of geen gewigte		77
2. Lae herhalings ("reps") met with swaar gewigte		78
3. Ek doen geen addisionele versterking nie		79
4. Ander (asseblief spesifiseer)		1
....		
....		

Vraag 20

WAARVANDAAN KRY U OEFENINGE. *merk ALLES toepaslik*		
1. Voorgeskryf deur 'n biokinetikus, maar ek oefen self		2
2. Ek oefen onder toesig van 'n biokinetikus		3
3. Ek oefen onder toesig van 'n fisioterapeut		4
4. Voorgeskryf deur 'n fisioterapeut, maar ek oefen self		5
5. "Trainer" (b.v. By die gim)		6
6. Atletiek afrigter		7
7. I kry my oefeninge via media (b.v. Tydskrif/internet)		8
8. Ek doen geen oefeninge nie		9
9. Ander (asseblief spesifiseer)		10

....

....

Vraag 21

HOEVEEL KILOMETER PER WEEK DRAF U IN DIE "AF-SEISOEN". *merk SLEGS een*		11
1. 10-29 Kilometer		
2. 30-40 Kilometer		
3. 40-50 Kilometer		
4. 50-60 Kilometer		
5. 60+ Kilometer		
6. Ek draf nie in die af-seisoen nie		
7. Ander (spesifiseer asseblief)		

....

....

Vraag 22

HOE HERSTEL (RECOVER) U NA 'n "LONGRUN"? *Merk SLEGS een*		12
1. Ek rus vir een dag heeltemal van ALLE oefeninge		
2. Ek rus 'n paar dae van ALLE oefeninge		
3. Ek rus nie, ek draf die volgende dag soos gewoonlik		
4. Aktiewe rus vir een (1) dag (b.v. Fietry/swem)		
5. Aktiewe rus vir veelvuldige dae (b.v. Fietry/swem)		
6. Ek oefen soos gewoonlik, maar gaan vir sportmasserings		
7. Ander (asseblief spesifiseer)		

....

....

Vraag 23

HOE HERSTEL ("RECOVER") U NA 'N MARATHON/ULTRA-MARATHON*?* ***merk SLEGS een***		13
1. Ek rus van ALLE oefeninge vir een (1) dag		
2. Ek rus van ALLE oefeninge vir veelvuldige dae		
3. Ek rus nie, ek volg my oefenprogram soos gewoonlik		
4. Aktiewe rus vir een (1) dag (b.v. Fietsry/swem)		
5. Aktiewe rus vir veelvuldige dae (b.v. Fietsry/swem)		
6. Ek gaan vir 'n sportmassering, maar oefen soos gewoonlik		
7. Ander (asseblief spesifiseer)		

....

....

Vraag 24

HOEVEEL KILOMETERS (km) HET U GEDRAF IN HIERDIE LAASTE WEEK (7 DAE) VOOR DEELNAME AAN DIE STUDIE?		14
merk SLEGS een		
1. 1-10 KM		
2. 10-20KM		
3. 20-40 KM		
4. 40-60 KM		
5. 60 + KM		
6. EK HET NIKS GEDRAF IN DIE LAASTE WEEK NIE		

DIE EINDE.....DANKIE

OFFICIAL USE

Identification number

1	2

Name: ....

Instruction:

Please mark with "X" the appropriate box.

Multiple answers may be marked

There are no right or wrong answers.

Should your choice not be reflected, display your answer at the "other" box.

You may skip answers you do not feel comfortable answering.

Your answers will not affect your relationship with the researcher or institution

OFFICIAL USE

Question 1

Age: ....years

3	4

Question 2

LEVEL OF RUNNING PARTICIPATION: ***mark ONLY ONE*** — 5

1. Recreational	
2. Competitive (competing in races)	
3. Professional	
4. Elite (national/international)	
5. Other (please specify)	

....

....

Question 3

HAVE YOU HAD ANY PREVIOUS SURGERY? m*ark ALL applicable*

1. Previous abdominal surgery		6
2. Previous spinal surgery		7
3. Previous hip surgery		8
4. Previous knee surgery		9
5. Previous pelvic surgery		10
6. None		11
7. Other (please specify)		12

....

....

Question 4

DO YOU SUFFER FROM ANY MEDICAL CONDITIONS THAT MAY AFFECT JOINTS OR MUSCLES? ***Mark ALL applicable***

1. Arthritic conditions (e.g. Rheumatoid ,osteoarthritis, lupus)		13
2. Osteoporosis		14
3. None		15
4. Chronic use of cortisone		16
5. Other (please specify)		17

....

....

Question 5

HAVE YOU GIVEN BIRTH? ***Mark ONLY one*** 18

1. Yes, normal birth	
2. Yes, cesarean section	
3. Yes, both normal and cesarean section	
4. No	

Question 5.1.

IF YOU ANSWERED "yes" IN QUESTION 5, HOW MANY TIMES HAVE YOU GIVEN BIRTH?
(if "no" please proceed to question 6) ***mark ONLY one*** 19

1. Once	
2. Two times or more	

Question 6

PLEASE INDICATE AREA(S) OF PREVIOUS INJURY. (Please note: in this case refers to an injury or ailment preventing you from one week (7days) of usual running. ***Mark ALL applicable.IF NO INJURY,PLEASE CONTINUE TO QUESTION 8***

1. Low back pain/injury		20
2. Hip pain/injury		21
3. Pelvic/groin pain or injury		22
4. Knee pain/injury		23
5. Ankle pain/injury		24
6. Foot pain/injury		25
7. No previous injury		26
8. Other (please specify)		27

....

....

Question 7

HOW DID YOU REHABILITATE THE INJURIES IN QUESTION 7?

mark ALL applicable. **If no previous injuries, proceed to question 8**

1. I did general exercises for that area only		28
2. I did specific exercises for that area along with exercises for the back, stomach muscles and legs		29
3. I sought professional advice and management (e.g. Physiotherapist,doctor, biokineticist)		30
4. I continued with running as soon as the pain/injury allowed		31
5. Rest		32
6. Other (please specify)		33

....

....

Question 8

DO YOU SUFFER FROM EXERCISE INCONTINENCE? (URINE LEAKING WITH EXERCISE)?

mark ALL applicable

1. During longer runs and marathons/ultra-marathons		34
2. During weight-training		35
3. During any exercise/running		36
4. During everyday activities		37
5. I do not suffer from exercise incontinence		38
6. Other (please specify)		39

....

....

Question 9

WHAT TYPE OF RUNNING SHOE DO YOU USE? ***mark ALL applicable***

1. Neutral		40
2. Minimalistic shoe (e.g. Newton)		41
3. I use a variety		42
4. Anti-pronating		43
5. Other (please specify)		44

....

....

Question 11

WHAT SURFACE DO YOU RUN ON DURING TRAINING? m*ark ALL applicable*

1. Tarmac 46
2. Off-road such as trials, dirt roads 47
3. Any surface 48
4. I change in between different surfaces 49
5. Grass 50
6. Other (please specify) 51

....

....

Question 12

HOW MANY KILOMETERS DO YOU RUN PER WEEK IN THE LAST 6 WEEKS BEFORE A MARATHON?

.................................kilometers 52 53

Question 13

ON AVERAGE,HOW MANY DAYS PER WEEK DO YOU RUN IN THE "RUNNING SEASON"? *mark ONLY one* 55

1. 7 days/week
2. 5-6 days/week
3. 3-4 days/week
4. 1-2 days/week

Question 14

HOW DO YOU INCREASE YOUR TRAINING MILEAGE ? *mark ALL applicable*

1. I run one (1) extra day 56
2. I add multiple days 57
3. I increase my kilometres gradually at about a 10% increase 58
4. I run an extra session per day 59
5. I add sharp increases in the kilometres of certain days 60
6. Other (please specify) 61

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Question 15

WHAT IS YOUR AVERAGE *TRAINING* PACE DURING A LONG SLOW DISTANCE RUN (DISTANCES 25+ KILOMETRES)? *mark ONLY one* 62

1. 4 - 5 minutes per kilometre
2. 5 - 6 minutes per kilometre
3. 6 - 7 minutes per kilometre
4. 7 - 8 minutes per kilometre
5. 8+ minutes per kilometre
6. Other (please specify)

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Question 16

WHAT IS YOUR AVERAGE *RACE* PACE FOR A MARATHON? mark ONLY one

1. 4 - 5 minutes per kilometre		63
2. 5 - 6 minutes per kilometre		
3. 6 - 7 minutes per kilometre		
4. 7 - 8 minutes per kilometre		
5. 8+ minutes per kilometre		
6. Other (please specify)		

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Question 17

EXERCISES IN YOUR TRAINING PROGRAM OTHER THAN RUNNING. *mark ALL applicable*

1. Cross-training (i.e. spinning, cycling, swimming)		64
2. Training for other endurance activities (e.g. Triathlons, cycling races)		65
3. Muscle training (e.g. Weights, Pilates, physic-ball at the gym or home)		66
4. Nothing, I only run		67
5. Other (please specify)		68

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Question 18

WHAT TYPE OF MUSCLE TRAINING EXERCISES DO YOU DO? *mark ALL applicable*

1. Squats and lunges		69
2. Abdominal (stomach) muscle exercises		70
3. Physio-ball exercises		71
4. Jumps and stair drills		72
5. Pelvic floor exercises		73
6. Circuit training for entire body		74
7. No muscle training exercises		75
8. Other (please specify)		76

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Question 19

HOW DO YOU TRAIN YOUR MUSCLES? *mark ALL applicable*

1. High repetitions with lighter or no weights		77
2. Low repetitions with heavy weights		78
3. I do no additional muscle training		79
4. Other (please specify)		1

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Question 20

WHERE DOES YOUR MUSCLE TRAINING EXERCISES COME FROM? ***mark ALL applicable***

1. Prescribed by a biokineticist, but I train on my own		2
2. I exercise under supervision of a biokineticist		3
3. Prescribed by a physiotherapist, but I train on my own		4
4. I exercise under supervision of a physiotherapist		5
5. Trainer (e.g. At the gym)		6
6. Athletic coach		7
7. I get my exercises from the media (e.g. Internet or magazine)		8
8. I do not train my muscles		9
9. Other (please specify)		10

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Question 21

HOW MANY KILOMETRES PER WEEK DO YOU RUN IN YOUR "OFF-SEASON"?***mark ONLY one*** 11

1. 10-29 Kilometres	
2. 30-40 Kilometres	
3. 40-50 Kilometres	
4. 50-60 Kilometres	
5. 60+ Kilometres	
6. No running	
7. Other (please specify)	

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Question 22

HOW DO YOU RECOVER AFTER A ***LONG RUN AS TRAINING? mark ONLY one*** 12

1. I rest from any exercises for one day	
2. I rest from any exercises for multiple days	
3. I do not rest, I continue with running the next day	
4. I rest by doing cross-training (e.g. Cycling, swimming) for one day	
5. I rest by doing cross-training (e.g. Cycling, swimming) for multiple days	
6. I continue with usual training, but get sport massages	
7. Other (please specify)	

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Question 23

HOW DO YOU RECOVER ***AFTER A MARATHON OR ULTRA-MARATHON? mark ONLY one*** 13

1. I rest from any exercises for one day	
2. I rest from any exercises for multiple days	
3. I do not rest, I continue with running the next day	
4. I rest by doing cross-training (e.g. Cycling, swimming) for one day	
5. I rest by doing cross-training (e.g. Cycling, swimming) for multiple days	
6. I continue with usual training, but get sport massages	
7. Other (please specify)	

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Question 24

HOW MANY KILOMETERS (km) DID YOU RUN IN THIS WEEK (7 DAYS)PRIOR TO THIS STUDY? *mark ONLY one*		14
1. 1-10 KM		
2. 10-20KM		
3. 20-40 KM		
4. 40-60 KM		
5. 60 + KM		
6. I DID NO RUNNING IN THE LAST WEEK (7 DAYS)		

THE END.....THANK YOU

ADDENDUM F

DATA FORM: BASELINE MEASUREMENT

OFFICIAL USE		OFFICIAL USE
Identification number		1 2

Name:....................................

1. EMG: Pelvic floor

	µV				
First measurement					
Second measurement					
Third measurement					
Average	3	4	5	6	7

2. EMG: Tr. A.

	µV				
First measurement					
Second measurement					
Third measurement					
Average	8	9	10	11	12

3.Pressure biofeedback

LEVEL
13

4. Anterior/ flexor muscles

	SECONDS		
First measurement			
Second measurement			
Third measurement			
Average	14	15	16

5. Lateral muscles (dominant)

	SECONDS		
First measurement			
Second measurement			
Third measurement			
Average	17	18	19

6. Lateral muscles

	SECONDS		
First measurement			
Second measurement			
Third measurement			
Average	20	21	22

7. Posterior/extensor muscles	SECONDS		
First measurement			
Second measurement			
Third measurement			SECONDS
Average			
			23 24 25
8. Body mass index = kg/m^2			BMI
Weight	KILOGRAMS		26 27
Length	CENTIMETRES		

ADDENDUM G

PRESSURE BIOFEEDBACK SCORING LEVELS

LEVEL	***DEFINITION***
1	*In crook lying an abdominal hollowing manoeuvre preset the abdominal muscles and the participant slowly raises one leg to a position of 100° of hip flexion with 90° knee flexion. The other leg is slowly raised to a similar position. This is the start position for the following four levels.* For the purpose of this study, the dominant leg will commence the start position to standardize repeat testing.
2	*From the start position, the participant slowly lowers one leg and, with the heel down on the plinth, Slide the leg out to straighten the knee, then slide it back up into the start position.*
3	*From the start position, the participant slowly lowers one leg and, with the heel maintained approximately 12cm off the plinth, fully extends the leg and then moves it back to the start position.*
4	*From the start position, the participant lowers both legs together and, with the heels down on the plinth, slide the legs out to straighten the knees and then slide them back and raise them to the start position.*
5	*From the start position, the participant simultaneously extends both legs keeping the heels approximately 12cm off the plinth and then flex the legs back to the start position.*

ADDENDUM H

DATA FORM: POST-EXERCISE MEASUREMENT

	OFFICIAL USE

Name:...

DATA

1. EMG: Pelvic floor

	µV				
First measurement					
Second measurement					
Third measurement					
Average					

µV				
28	29	30	31	32

2. EMG: Tr. A.

	µV				
First measurement					
Second measurement					
Third measurement					
Average					

µV				
33	34	35	36	37

3. Pressure biofeedback

LEVEL

LEVEL
38

4. Anterior/ flexor muscles

	SECONDS		
First measurement			
Second measurement			
Third measurement			
Average			

SECONDS		
39	40	41

5. Lateral muscles (dominant)

	SECONDS		
First measurement			
Second measurement			
Third measurement			
Average			

SECONDS		
42	43	44

6. Lateral muscles

	SECONDS		
First measurement			
Second measurement			
Third measurement			
Average			

SECONDS		
45	46	47

7. Posterior/extensor muscles
First measurement
Second measurement
Third measurement
Average

SECONDS		

SECONDS		
48	49	50

8. Distance completed

KM	
51	52

ADDENDUM I

NORMATIVE DATA FOR FUNCTIONAL CORE TESTS

Functional test: Mean endurance times in seconds	***Men***	***Women***
Extension	161	185
Flexion	136	134
Right side bridge	95	75
Left side bridge	99	78
Flexion/extension ratio	0.84	0.72